MODELING OF EXTRUSION THROUGH CURVE DIE

A

THESIS SUBMITED IN PARTIAL FULFILMENT
OF THE REQUREMENT FOR THE DEGREE OF

Master of Technology

In

Mechanical Engineering

By

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(Specialization: Production Engineering)

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
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CERTIFICATE

This is to certify that the thesis entitled, "**MODELING OF EXTRUSION THROUGH CURVE DIE**" submitted by **Mr. Mahendra Singh Pachalasiya** in partial fulfillment of the requirements for the award of Master of Technology in Mechanical Engineering with Production Engineering specialization during session 2012-2013 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

It is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:
Place: Rourkela

Prof. K. P. Maity
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Orissa, India

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DATE: **MAHENDRA SINGH PACHALASIYA**

ABSTRACT

Extrusion is a metal forming process, In this process the material is pushed or drawn through a die of desired cross-section to create long object of a fixed cross-section area, extrusion may be continuous (producing infinitely long material) or semi continuous (producing many pieces). The extrusion process can be done with the material hot or cold. There is gradual deformation which results in the uniform microstructure. Anon-linear converging cosine dies profiles are used for square to square extrusion process. Extrusion through mathematically contoured die plays a critical role in improvement of surface finish of extruded product. The cosine die profile designed using CATIA, Solidworks and MATLAB was used to find out the coordinate of the cosine die profile and solid model was generated using CATIA the STL files of extrusion dies generated by solid work and CATIA. The STL files are used in DEFORM-3D Software for FEM simulation. The work piece, punch and container with cosine die profiles are used in DEFORM-3D software for simulation purpose. Extrusion was assumed to be isothermal condition, for extrusion purpose Al-6062 work material are used in DEFORM-3D Software. FEM modeling determine damage Strain-effective (mm/mm), strain rate-effective ((mm/mm)/sec), stress-effective (MPa), stress-Max principal (MPa), Velocity Total Vel (mm/sec) and Temperature (C^0). The results optioned during FEM simulation of Al-6062[FEA] are compared with the FEM simulation results of Tellurium Led [FEA]. For Extrusion process of Al-6062, the Extrusion load and pressure are more as compared to extrusion of Tellurium Lead under same percentage of Reductions and comparisons of load and pressure between Aluminum and Tellurium Lead during deformation process.

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CHAPTER 1

INTRODUCTION

1.1 METAL FORMING

Forming is the processes in which the wanted shape and size are achieved through the plastic deformation of a material .The stressed induced during forming process are greater than the yield strength, But less than the fracture strength of the material. Metal Forming operations such as forging, Rolling, Drawing etc. are capable of yielding high productivity compare to other metal working techniques. Metal forming is one of the most important process in manufacturing of a large variety of products. Metal forming or metal working process are divided into two parts; Bulk forming and sheet metal forming. The Bulk forming refers to processes like Forging, Rolling **Extrusion** etc. where there is a controlled plastic flow of material into required shapes. Forming process can be divided into three categories.

Cold Working $< 0.4\ T_m$

Warm Working $0.4 - 0.6\ T_m$

Hot Working $> 0.6\ T_m$

Where T_m is melting point of material (K)

Cold Working is a process in which the material is deformed below recrystallization temperature and hot working is a process in which the materials deform above the recrystallization temperature. And worm working is a process in which the material deforms at a recrystallization temperature.

Cold working products will be stronger then the hot working process due to work hardening. In cold working process there will not be any shrinkage so better dimensional accuracy products will be produced. In cold working process hard and brittle materials excessive load will appear that why this process uneconomical and hot working is used for such materials. Industries mostly depend on metal forming operations to reduce or minimize the material losses. The advantages of metal forming processes are as follows;

a. In this process wanted shape and size are obtained through the plastic deformation of materials.
b. It’s a very cheap process where the wanted shape, size and surface can be obtained without any scrap or loss of material.
c. Strain and hardness are increased due to strain hardening.
d. The input energy can be well-spent, utilized in improving the strength.

In metal forming process the analysis of the stresses are important areas of plasticity. The forces [25] and deformation generally are quite complex. It is usually useful to make simpler assumptions to obtain a solution. The strain involved in plastic deformation process is very large, usually it is possible to neglect elastic strain and consider only the plastic strain (rigid-plastic region). The strain hardening is also neglected. The principal use of analytical study of metal working process is for determining the forces required to produce a given deformation for a certain geometry prescribed by the process and the ability to make an accurate strain, stress and velocity at every point in the deformation region of the billet or work piece. The calculations are useful for selecting or designing the equipment to do a particular job. In general any theory consists of three sets of equations.

- ✓ Static equilibrium of the force equation
- ✓ Levy mises equation
- ✓ Yield criterion

The most analysis of actual metal working process is limited to two dimensional, symmetrical problems.

1.2 Slab method of analysis

This method assumes that the metal deforms homogeneously in the deformation zone. A square lattice placed in the deformation zone would be inaccurate into four-sided elements. It is the easiest method and widely used in strength of material. It calculates the inhomogeneity due to friction but neglects the inhomogeneity due to friction at the die-work piece interface and also the influence of transverse stress. It calculates the average forming stress from the work of plastic deformation.

1.2.1 Slip line field theory

This method adopts or assumes the nonhomogeneous deformation and it is based on the element that any general state of stress in plain strain consists of pure shear plus a hydrostatic pressure. Slip line is in element of two [29] dimensional vector diagram, which shows the deviation of maximum shear stress identified with the direction of slip at any point. Slip line is always a network of lines passing through each other at right angle .It is made up by trial and error method.

1.2.2 Lower bound solution

The power of deformation calculated from statistically admissible field which satisfies the Stress equilibrium and yield criterion is always lower than the actual one, it is called lower bound solutions. Lower bound solutions are those, which provide values for the total power, which are lower than the actual one. Here the first step is the design of a stress tensor, which is far more difficult to look on. It is more complex to examine, so less work has been achieved. For lower bound, the requirements are more stress free and the following conditions are not necessarily fulfilled. No need to maintain compatibility, No need to satisfy stress strain relation and Geometrical boundary condition don’t have to be satisfied thus, only equation of equilibrium, yield criterion and statistical boundary conditions only wants. The assumed stress field i.e. velocity field is never of such universal form as to take in all admissible fields due to our limited capability in handling the mathematics in the most universal form.

1.2.3 Upper bound solution

An upper bond analysis provides an over estimation of the required deformation force. It is more accurate because, it will always result in an over estimation of the load that is press or the machine will be called upon to deliver. In this case factor of safety will be automatically built. In this analysis, the deformation is assumed to take place by rigid body movement of square blocks in which all particles in a given element moves with the some velocity. A kinematically admissible velocity should satisfy the

- ✓ Continuity equation
- ✓ Velocity boundary condition
- ✓ Volume constancy condition

The power of deformation calculated from this is higher than the actual one, called upper bond. When applying upper bond, the first step is to consider of a velocity field for the deforming body.

- ✓ The field can be easily imagined and related to our visual experience.
- ✓ Velocity can be measured directly and easily showed in a physical manner.
- ✓ In this case factor of safety is automatically in made.
- ✓ It is quite easy to analyze.

1.2.4 Finite element analysis

The finite element analysis method denotes an extension of matrix method for the analysis of framed structures to the analysis of the continuum structure. The basic idea of this method is to substitute the structure i.e. the range having an infinite or unlimited number of unknowns by a mathematical model, which has a limited or finite number of unknowns at sure select distinct points. This method is very powerful as it helps to exactly analyze structures with complex geometrical properties and loading condition. In finite element method, a structure or a continuum is discretized and idealized by using a mathematical model, which is an assembly or subdivision or discrete elements. These elements known as finite elements are assumed to be connected only at the joints called nodes. Simple functions such as polynomials are select in terms of unknown displacements and their derivative at the nodes to the approximate over the variation of the actual displacements over each finite element. The external loading is also transformed into equivalent forces applied at the nodes, the performance of each element independently and later as an assembly of these elements is obtained by relating their response to that of the nodes in such a way that the following basic conditions are satisfied at each node.

The equation, which are found using above condition and then these modified equations are solved to find displacements at the nodes, which are the basic unknowns of the finite element method. Finite element method [25] contains wide computations mostly repetitive in nature. Hence, this method is suitable for computer programming and results. These problems can be obtained easily using programming on electronic digital computers. Finite element computer programs have become widely available, easier to use and can display results with good-looking photographs. Even a useless user can produce some kind of answer. It is hard to disbelieve finite element results because of the effort needed to get them and the polish of this presentation. However, smooth and colourful stress lines can be produced by any model, good or bad. It is possible that maximum finite element analyses are so flawed that they cannot be trusted. Even a poor mesh, improper element type, incorrect loads or improper supports may produce results that appear reasonable in causal inspection. A responsible user must understand the physical nature of the problem and the behaviour of finite element well enough to prepare a suitable model and evaluate the quality of results.

1.3 Extrusion

Extrusion is an often used forming process among the different metal forming operations and its industrial history dates back to the 18th century. A billet (work piece) is placed in the container and pressed by the punch, after pressing the metal to flow through a die with an opening. In process of extrusion, a billet is placed in an enclosed chamber. The chamber has an opening through which the excess material escapes as the volume of chamber is reduced when pushed by ram (punch). The escaped material has a uniform cross section identical with that of the opening. In general extrusion process is used to produce cylindrical bars or hollow tubes. A large variety of irregular cross sections are also created by this process using dies of complex shapes. The process has accuracy and firmness, in this process large reduction achieved even at high strain rates has made it one of the fastest growing metal working methods. In extrusion process [25] more force is required. The most metals are extruded hot when the deformation resistance of the metal is low. However cold extrusion is also possible for many metals and has become an important commercial process. The reaction of the workspace with the container and the die result in high compressive stress that effectively reduces cracking of the materials during primary breakdown from ingot. This is an important reason for increased commercial adaptation of extrusion in the working of metal difficult to such as stainless steel, nickel, nickel based alloy and other high temperature materials. More than 10 years ago researchers started to attracted by the 3D problems in metal forming now-a-days 3D modeling is still regarded as a highlighted and difficult problem. The different methods of analysis extended to 3D, among which the finite element analysis is most commonly used. Most of the results that have been published on three dimensional finite element method simulations are based on software package like DEFORM-3D.

EXTRUSION PROCESS

It is a plastic deformation process in which a block of billet is forced to flow by compression through [24] the die opening of a smaller cross-sectional area. Show in Fig. 1.1.

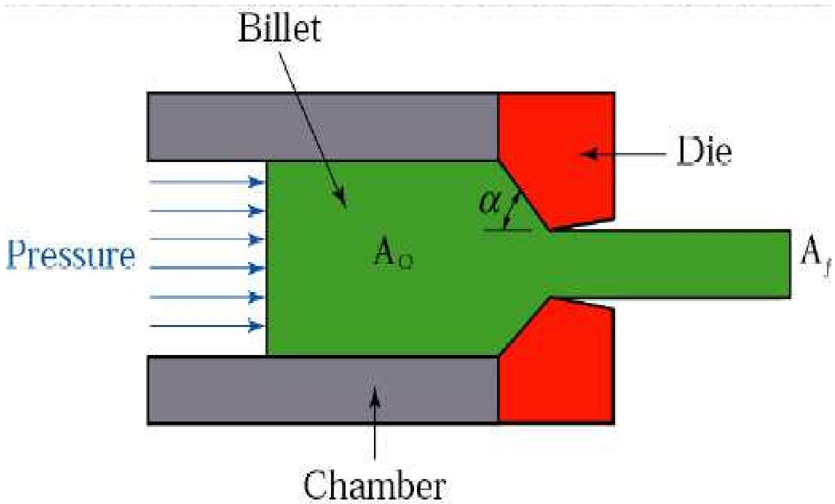


Fig. 1.1 Principal of extrusion process

The forcing of solid metal or workpiece through a suitable shaped orifice under compressive forces, extrusion is slightly similar to squeezing toothpaste through a tube, although some cold extrusion processes more nearly look like forging, which also deforms metals by application of compressive forces. Most metals can be extruded, although the process may not be economically feasible for high-strength alloys. The most widely used method for producing extruded shapes is the direct, hot extrusion process. In this process, a heated billet of metal is placed in a cylindrical chamber or rectangular chamber and then compressed by a hydraulically operated ram. The extrusion of cold metal is variously termed cold pressing, cold forging, cold extrusion forging, extrusion pressing and impact extrusion. The cold extrusion has become popular in the steel fabrication industry, while is widely used in the nonferrous field. The advantages of cold extrusion are higher strength because of severe strain-hardening, good surface finish, dimensional accuracy and economy of the product and minimize the machining requirement of the output product.

The classification of extrusion processes are as follows,

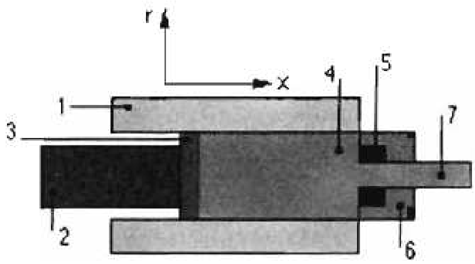
There are several ways to classify metal extrusion processes;

- ✓ By direction:-Direct / indirect extrusion or forward /backward extrusion.
- ✓ By operating temperature: - Hot /cold extrusion.
- ✓ By equipment: - Horizontal and vertical extrusion.

1.3.1 DIRECT AND INDIRECT EXTRUSIONS

Direct extrusion

In direct extrusion [28] the metal billet is placed in a container and driven through the die by the ram or punch and friction is at the die and container wall requires higher pressure than indirect extrusion process. The dummy block or pressure plate is placed at the end of the ram in contact with the billet. Fig. 1.2 Shows a direct extrusion process.

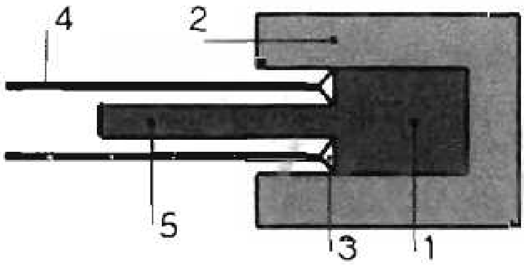


1 Container
2 Ram
3 Dummy block,
4 Billet
5 Die
6 Die holder
7 Extruded product.

Fig. 1.2 Direct Extrusion

Indirect extrusion

The hollow ram containing the die is kept stationary and container with the billet is caused to move and the friction at the die only (there is no relative movement at the container wall) requires constant pressure and the hollow ram limits the applied load. Fig. 1.3 Shows the indirect extrusion process.



1 Billet
2 Container
3 Die
4 Ram
5 Extruded product.

Fig. 1.3 Indirect Extrusion

1.3.2 FORWORD, BACKWORD AND COMBINED EXTRUSIONS

Forward extrusion

In this process Metal is forced to flow in the same [26] direction as the punch and the punch closely fits the die cavity to prevent backward flow of the material. Fig. 1.4 shows the forward extrusion process.

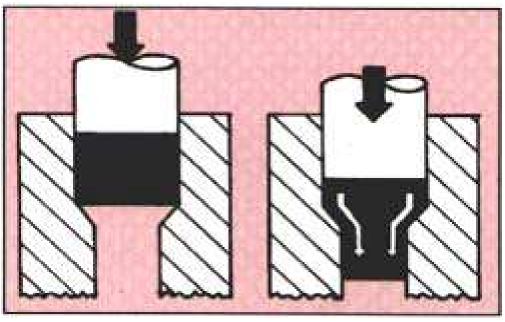


Fig. 1.4 Forward extrusion process

Backward extrusion

In this process Metal is forced to flow in the direction opposite to the punch movement and metal can be forced to flow into recesses in the punch shown in the Fig. 1.5.

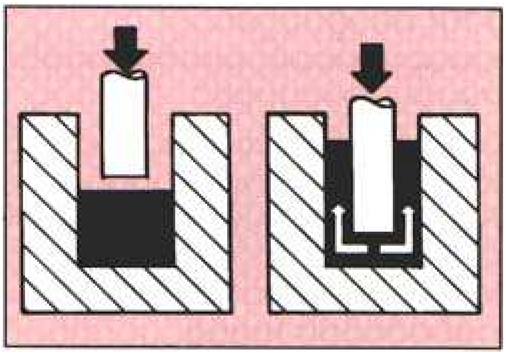


Fig. 1.5 Backward extrusion process

Combination of backward and forward extrusion

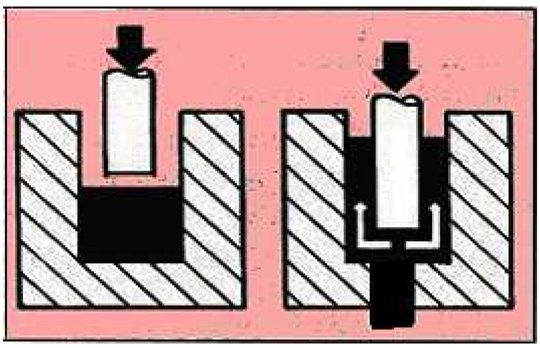


Fig. 1.6 Combination of backward and forward extrusion

1.3.3 COLD EXTRUSION AND HOT EXTRUSIONS

Cold extrusion

Cold extrusion process done at room temperature or slightly elevated temperatures. This process can be used for most material subject to designing strong sufficient tooling that can withstand the stresses crested by extrusion. The metals that can be extruded are lead, tin, aluminum alloy, copper, titanium, molybdenum, vanadium steel. Examples of cold extruded part are collapsible tubes aluminum can, cylinders gear blanks.

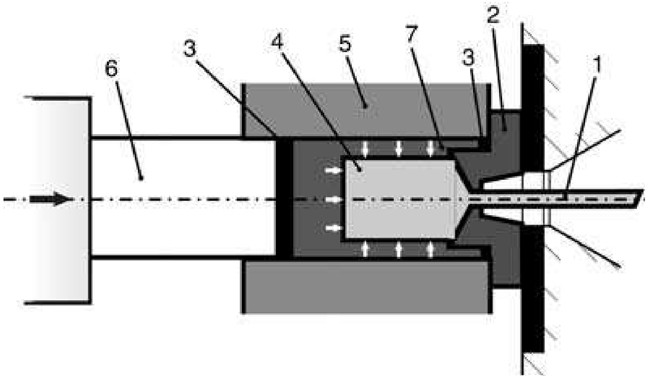
Hot extrusion

Hot extrusion is done at high temperatures about 50 - 70 % of the melting point of the work piece material and the pressure range about 35-700 MPa. The Most commonly used extrusion process is the hot direct extrusion process the cross-section shape of the extrusion is defined by the shape of the die. High temperatures and pressures affect die life as well as other components. In hot extrusion process good lubrication is required. Oil and graphite work at low temperatures whereas at higher temperatures glass powder is used.

1.3.4 HYDROSTATIC AND IMPACT EXTRUSIONS

Hydrostatic extrusion

In hydrostatic extrusion process the billet is smaller in diameter than the chamber, which is filled with a fluid and the pressure is transmitted to the billet by a ram or punch and during this process billet does not come in contact with the piston and the material is deformed due to development of hydrostatic pressure within the fluid hydrostatic pressure increase the ductility, and very good quality products can be extruded by this process. Hydrostatic extrusion can be done hot warm or cold and can be used to extrude **brittle** materials. That cannot be handled by conventional extrusion process. It can be seen in the fig. 1.7 given below.



1. Extrusion,
2. Die,
3. Seal,
4. Billet,
5. Container,
6. Stem,
7. Hydrostatic medium.

Fig. 1.7 Hydrostatic extrusion

Impact extrusion

Impact extrusion comes into cold extrusion process, in this process a heavy punch is allowed to fall over the material and material takes the shape of the die by following the clearance between punch and die. This is used [27] to make collapsible tubes of soft alloys as tooth paste containers made by this process. This process is limited to **soft and ductile** materials. It can be seen in the fig. 1.8 Shown below;

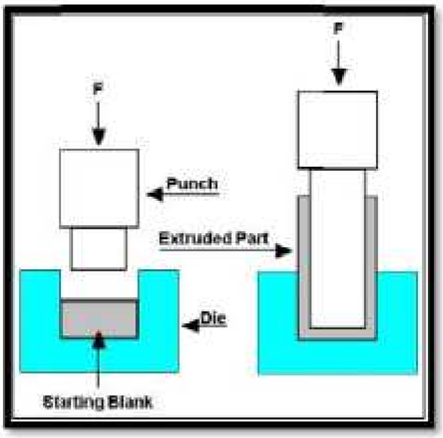


Fig. 1.8 Impact extrusion

1.4 Advantage of extrusion

In the different metal forming processes, Extrusion has definite advantages over others for the production of three dimensional section shapes. Now it is becoming essential to pay more attention to the extrusion of section rod from round stock.The process is also attractive because press machines are readily available and the necessity to purchase expensive section stock corresponding to a multiplicity of required sections is eliminated. There are many advantage of extrusion as follows;

- ✓ Uniform cross-section areas obtain in whole process.
- ✓ Strain and hardness are increased due to strain hardening.
- ✓ Low cost of die and it’s economical to make small quantities of a shape and size.
- ✓ Good surface finish obtained by any other metal forming process.

1.5 Limitation of Extrusion

- ✓ Extrusion is limited to only a few metals and cannot be done any chosen material.
- ✓ Most materials require high temperature and pressure which makes equipment costly.
- ✓ During extrusion process die material should be able to withstand the load, high temperature and wear.
- ✓ In the case of steel extrusion process the equipment is costlier due to the magnitude of temperature to which the metal must be heated (2300F).
- ✓ In indirect extrusion complicates the handling of extruded or output parts.

1.6 Application of extrusion

Extrusion is one of the most important methods of metal forming process with we can produce many product of high industrial applications with good quality. Some of the applications of the extrusion process are given below;

- ✓ Railing for sliding doors.
- ✓ Tube for various cross-sections.
- ✓ Structure and architectural shapes.
- ✓ Doors and window frames.
- ✓ Extrusion process used to make collapsible tubes of soft alloys such as tooth paste containers.

CHAPTER 2

LITERATURE SURVEY

This chapter contains research paper related to extrusion process using Upper-Bond method and Finite Element Analysis Method, modeling and simulation of extrusion through curve die.

Maity et al. [1] Extrusion through mathematically contoured die plays a critical role in improvement of surface integrity of extruded product. There is gradual deformation during extrusion process which results in the uniform microstructure. In the recent investigation non-dimensional extrusion pressure and optimum die length for cosine die profile has been obtained by three dimensional (3D) upper bound method using dual stream function method for different-different reductions. Thetheoretical modeling has been validated with experiments. The experimental results are found to be compatible with the theory. Recently the process design involving mathematically contoured die profile has drawn the attention of various researchers to improve not only dimensional accuracy but also quality of products. Richmond and Devenpeck [2] first conceptualized an ideal die of perfect efficiency and developed the governing equations for metal flow. Later, Richmond and Morrision [3] used the above concept to design stream-lined wire-drawing dies of minimum length with sigmoidal die shape. The total work of deformation is equal to that for homogeneous compression with redundant work at entry and exit equal to zero. Upper bound solutions for extrusion through axisymmetric curved dies have been investigated by Chen and Ling [4] and Chang and Choi [5]. The upper bond solutions with experimental flow studies through different axisymmetric curved die have also been reported by Mata-Pietri [6] and Frisch [7]. Lee et al. [8] designed an optimal Bezier shaped curve die profile that yield more uniform microstructure. Rani Kainew et al. [9] investigated finite element analysis of copper extrusion process in both flat faced and converging dies profile. In the present investigation a three-dimensional upper bound analysis using dual stream function has been carried out for extrusion of square section from square billet using cosine die profile.

Dewan et al. [10] the kinematic-ally admissible velocity and strain rate field were established to extrusion and drawing through elliptical die profile. This paper related to establish continuous velocity field. Ameed et al. [11] used a new analytical method to calculated relative deformation energies for complex die shape by using Upper bound theory which is an important method to solve technical problem in the field of metal deformation.

Maity et al. [12] investigated an upper-bound analysis is proposed for the extrusion of square section from square billets through curve die having prescribed profiles. The lowest extrusion pressure was seen in the absence of friction during extrusion process. Samanta [13] investigated slip-line –field solutions for other die shapes this paper deals about extrusion through cosine- shaped die. Yih [14] In three dimensional for ideal fluid flow suggested the use of two stream functions in place of one as in the case of two- dimensional flow each stream functions represents a class of surface called stream surfaces. The intersection line of two stream surface, one taken from each class is a three dimensional stream line. Zhao et al.[15] investigation was related to the arbitrary Lagrangian-Eulerian (ALE) adaptive remeshing technology and the HyperXtrude software of transient finite element simulation used for simulation of aluminum extrusion process during simulation of Al damage .strain rate, stress, temperature, velocity of metal were obtained the result are basically same as a practical value During extrusion process. YAN et al. [16-17] presented the use of Al in industries are very high, because properties of Aluminums are very good. In extrusion process the defect of product can be eliminated by adjusting processing technique. LI G et al. [18] the finite element method was used to simulating the bulk forming process and DEFORM 3D [19-20] based on the updated lagrangian approach was used to achieve the field of damage, strain, strain rate, stress effective stress, max. principal stress, temperature, and velocity of metal flow. During this process obtained that the good combination between the finite element simulation value and the experimental value.

Gouveia et al. [21] investigated in our paper three dimensional forward extrusion process from a round billet to square section through a converging die and analyzed using both Lagrangian and the combined Eulerian-lagrangian finite element analysis. It was the good combination between physical and numerical modeling. In this paper finally concluded that the combined Eulerian-Lagrangian formulation is compatibility is more efficient than the Lagrangian formulation for analyzing a steady–state metal forming process, And during this simulation required less CPU time. Kuester et al. [22] investigate an integrated FORTRAN code was developed to compute the upper bound extrusion load using equation for any reduction (R) and friction factor (m) the program first calculates the velocity components and the strain rate components. The total power of deformation has been minimized using multivariable optimization technique.DEFORM-3D Version 6.1 (sp2), User's Manual, [23] Scientific Forming Technologies Corporation, The actual FEM-based analysis is carried out in this portion of DEFORM-3D. This simulation engine is based on a rigid-plastic FE formulation and can handle a multiple number of billets and dies with non-isothermal simulation capability. This is the programme which actually makes the numerical calculations for solution of the problem The pre-processor consist of (a) an input module for iterative data input verification, (b) an automatic mesh generation program which creates a mesh by considering various process related parameters such as movement of punch, friction, material properties, die and work piece geometry; and (c) an interpolation module that can interpolate various simulation results of an old mesh onto a newly generated mesh. The automatic mesh generation facilitates a continuous simulation without any intervention by the user. All the input data generated in the pre-processor can be saved (1) in a text form which enables the user to access the input data through any text editor; and/or (2) in a binary form which is used by the simulation engine. Bogale [24] designed a die using Solid Edge modeling software of a rectangular profile. To simulate the flow of polymers in the die using Comsol and To calculate the output mass flow rate and the operating point of the die. And also defined Extrusion and Principal of extrusion process, types of extrusion process, Bogale concluded that The Carreau model was used to analyse the die on COMSOL multi physics software and the die was designed for a LDPE plastic material at around 220 degree centigrade. Based on the extruder's screw parameter the flow rate in the extruder was calculated. This helps to obtain the pressure in the extruder. That is, when the pressure is at its minimum there will be maximum output and when the volume flow rate is at its minimum there will be maximum pressure. Even though the die has been optimized in order to get similar shear stress distributions across the die, it was not possible to simulate the exact dimensions of the die for a rectangular profile with Comsol.

Chaubey [25] investigated the modelling and design of die profile of extrusion of square section from round billet through non-linear converging dies. It is conclude that a non-linear converging die profile has been designed for extrusion of square section from round billet using cosine function in DEFORM-3D software. The extrusion load and Pressure increases with increase in reduction and friction factor. Load in case of split test is less as compared to solid work material under same experimental condition. The extrusion load for non-linear converging die is less as compared to linear converging die under same simulation condition. The flow of material in non-linear converging die appears to be gradual especially in higher reduction. Tirkey [26] worked in the area of three dimensional analysis of lateral extrusion of some complex forms and he is concluded the decreasing thickness of the head with a constant billet diameter and friction factor causes a higher relative extrusion pressure, The proposed simple kinematic-ally admissible velocity fields to describe the three-dimensional deformation have a qualitative agreement with the experimental results. The proposed velocity field gives higher load values than the values experimentally obtained within twenty five percent. The velocity field proposed in the present investigation can be used conveniently with short computational time for the prediction of extrusion loads & deformations in heading of different shapes. A higher order polynomial velocity field can be tested to get better results for different section.

Murmu [27] worked about three dimensional analysis of extrusion through taper die and concluded that The upper bound analysis of extrusion of different sections taper dies can carry out by using discontinuous velocity field (modified SERR technique). These techniques provided a better method of analysis for this type of section extrusion, which are difficult by the continuous velocity field formulation. The ideal die geometry (equivalent semi-cone angle) can be obtained for different area reductions and friction conditions. Comparison made with present theoretical and experimental results shows that the present solution can predict reasonable upper-bound extrusion pressure. The present method can be extended to obtain the solution of generalized problems of non-axisymmetric extrusion or drawing through taper dies. Carlos Fernando Cuellar Matamoros [28] worked about Modeling and control for isothermal extrusion of Aluminium. Within the aluminium industries, extrusion plays an important role. In this process, it is of superior importance to achieve uniform product quality while minimizing the discard. The exit temperature of the extrudate profile is a measure of product quality. It is desired to run the process in such a manner, that this temperature remains constant throughout the whole extrusion cycle. This is known as isothermal extrusion. Developing model-based control strategies to achieve isothermal extrusion was the aim of this thesis.

Rout [29] worked about a class of solutions for extrusion through converging dies and the present investigation is a sincere try to develop a class of solutions for extrusion of different sections from round and square billet through converging dies by three-dimensional upper bound method as well as Finite element method. Three dimensional upper bound solutions are based on both continuous velocity field and discontinuous velocity field. The continuous velocity fields are based on dual stream function method. The discontinuous velocity fields are based on SERR (spatial elementary rigid region) technique the results are compared with square or flat faced die. It is observed that there is drastic reduction in extrusion pressure in converging die. FEM modeling has been carried out extrusion of square sections from square billet using DEFORM-3D software. The die profiles of cosine, Bezier and polynomial shapes are considered. The rigid-plastic material model has been considered. The experiments have been conducted to verify the proposed theory partially. The extrusion test rigs have been fabricated to carry out extrusion through mathematically contoured dies. Experiments have been conducted both for dry and lubricated conditions. Skoog et.al [30] worked about the performing materials for aluminium extrusion components. Uddeholm Tooling is a global supplier of premium tool steel, higher quality grades of conventional tooling material and related services. An Uddenholm aim is to best partner for tool maker's tool users and their customers, with regards to tooling materials their treatment and their applications. Aubert et.al [31] worked about a new die material for longer service life; the lifetime of light alloy die cast parts highly depends on the thermal fatigue behaviour of the material. Aubert & Duval has created a grade for improved thermal fatigue resistance while maintaining high properties of resistance to abrasion at temperature.

OBJECTIVE OF THESIS

1. To design a die using a CATIA, Solid Works modelling software and Auto-CAD for a cosine profile curve die.
2. To analysis of load Distribution in Deformation process.
3. Analysis of stresses distribution in the deformation process
4. To design and develop an extrusion setup (Dies).
5. Comparison between the Extrusion Load and Extrusion pressure during extrusion of Tellurium lead [FEA] and AL-6062 [FEA] Results.

CHAPTER 3

UPPER BOUND METHOD

3.1 Formulation

The upper bound theorem conditions that the power estimated from Kinematic-ally-admissible velocity fields (KAVF) is always higher than the actual one. Amongst all kinematic-ally-admissible velocity fields the actual one minimizes the expression:

$$J=\left(\frac{2\sigma_0}{\sqrt{3}}\right)\int_V \sqrt{\left(\varepsilon_{ij}\varepsilon_{ij}\right)}\,dV+\left(\frac{\sigma_0}{\sqrt{3}}\right)\int_{S_i}|\Delta V|_{S_i}\,dS_i+\left(\frac{m\sigma_0}{\sqrt{3}}\right)\int_{SD_i}|\Delta V|_{SD_i}\,dS_{SD_i}\quad \dots \quad \dots\dots (1)$$

Where

J=power of dissipation rate

σ_0 = σ_f =flow stress

ε_{ij} = The derived strain rate tensor or

$|\Delta V|_{S_i}$=The velocity discontinuity at the entry and exit surfaces Si.

$|\Delta V|_{SD_i}$ = The velocity discontinuity at the die-metal interfaces SDi

m= friction factor.

The kinematic-ally admissible velocity field has been obtained using dual stream function method.

According to Yih [14], the velocity components can be derived from these stream functions using the equations.

$$V_x=\left(\frac{\partial\Psi_2}{\partial y}\right)\left(\frac{\partial\Psi_1}{\partial z}\right)-\left(\frac{\partial\Psi_1}{\partial y}\right)\left(\frac{\partial\Psi_2}{\partial z}\right)\quad \dots\dots\dots \quad \dots\dots \quad \dots \quad \dots\dots \quad \dots... \quad (2a)$$

$$V_y=\left(\frac{\partial\Psi_2}{\partial z}\right)\left(\frac{\partial\Psi_1}{\partial x}\right)-\left(\frac{\partial\Psi_1}{\partial z}\right)\left(\frac{\partial\Psi_2}{\partial x}\right)\quad \dots\ \dots \quad \dots \quad \dots \quad \dots \quad \dots\dots \quad \dots\dots \quad \dots(2b)$$

$$V_z=\left(\frac{\partial\Psi_2}{\partial x}\right)\left(\frac{\partial\Psi_1}{\partial y}\right)-\left(\frac{\partial\Psi_1}{\partial x}\right)\left(\frac{\partial\Psi_2}{\partial y}\right)\quad \dots\dots \quad \dots\dots \quad \dots\dots \quad \dots\dots \quad \dots\dots \quad .(2c)$$

To originate the dual stream functions for the current problem, the geometry shown in Fig. 3.1 with agreed reference system is considered. Because of symmetry about two mutually perpendicular axes, only one quadrant of the real deformation zone is considered, F(z) is the Die-profile function such that the Die faces in the x-z and y-z planes are represented by x=F(z) and y=F(z) respectively. The function F (z) must satisfy the conditions that the F(z)=W at z=0 and F(z)=A at x=L, where W and A are the semi width of billet and product respectively and L is the die length.

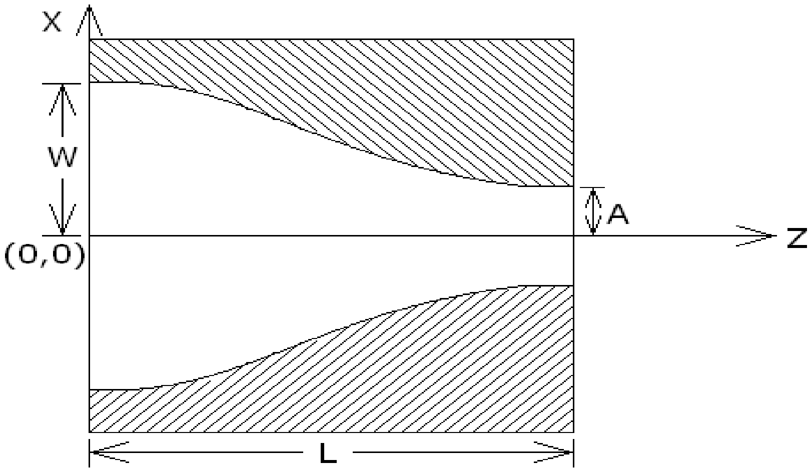


Fig. 3.1 Cosine profile curved Die

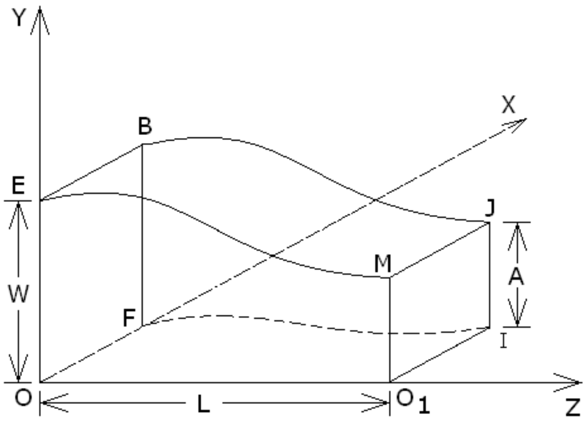


Fig. 3.2 One quadrant of the deformation zone

The dual stream functions Ψ_1 and Ψ_2 are chosen as shown below

$$\Psi_1 = -\frac{x}{F(z)} \quad \text{(3a)}$$

$$\Psi_2 = -\frac{W^2 V_b y}{F(z)} \quad \text{(3b)}$$

Where V_b=billet velocity. it can be verified that(i) Ψ_1=0 on the plane x=0 and Ψ_1= -1on the die surface plane x=F(z); and (ii) $\Psi_2 = 0$ on the plane y=0 and $\Psi_2 = W^2 V_b$(which is a constant) on the die surface y=F (z)). Such constant values ensure that surfaces x=0, x=F (z), y=0 and y=F (z) are stream surfaces, and as such velocity components normal to those surface vanish [1]. Thus, Ψ_1 and Ψ_2 defined in the above mentioned manner satisfy all velocity boundary conditions. Hence they are valid boundary conditions. Hence, they are valid stream functions to generate a Kinematically-admissible velocity field. Substituting Eq. (3) into Eq.(2) and simplifying, the velocity components in the deformation region are:

$V_x = \frac{W^2 V_b x F'}{F^3}$. .... (4a)

$V_y = \frac{W^2 V_b x F'}{F^3}$ ………… ………… ……… ……… …… ………… …… ……… (4b)

$V_z = \frac{W^2 V_b}{F^2}$ ……… ……… ……… ……… … ………… …… ………… …… …..(4c)

Where F=F(z)and $F' = \frac{dF}{dz}$

The strain-rate components ε_{ij} are derived from the velocity components using the relationship:

$\varepsilon_{ij} = \frac{1}{2}\left[\left(\frac{\partial V_j}{\partial x_j}\right) + \left(\frac{\partial V_i}{\partial x_j}\right)\right]$ ……… ….…. …… ……… …… …… …… …… ……(5)

The strain-rate components for the proposed flow field are as follows by substituting Eq. (4) in Eq. (5)

$\varepsilon_{xx} = \frac{(W^2 V_b F')}{F^3}$.

$\varepsilon_{yy} = \frac{(W^2 V_b F')}{F^3}$.

$\varepsilon_{zz} = \frac{(-2W^2 V_b F')}{F^3}$.

$\varepsilon_{xy} = \varepsilon_{yx} = 0.$

$$\varepsilon_{yz} = \varepsilon_{zy} = \left(\frac{1}{2}\right) W^2 V_b\, y \left[\left(\frac{F''}{F^3}\right) - \left(\frac{3(F')2}{F^4}\right)\right].$$

$$\varepsilon_{zx} = \varepsilon_{xz} = \left(\frac{1}{2}\right) W^2 V_b\, x \left[\left(\frac{F''}{F^3}\right) - \left(\frac{3(F')2}{F^4}\right)\right] \quad \ldots \quad \ldots \ldots \quad \ldots \ldots \quad \ldots \ldots \ldots \ldots \quad (6)$$

Where $F'' = \frac{d^2 F}{dz^2}$

From equation (6), it is marked that velocity field satisfy incompressibility state. Using Eq. (6), J can be calculated from Eq. (1) when the die-profile function, F, is known. For any reduction and friction factor m, J can be minimized with respect to suitable parameters to yield the best upper bound.

3.2 Die profile function

The die geometry examined in the present investigation is shown in Fig. (9). Referring to this figure, it may be seen that the die profile function F (z) is similar in both x- and y- direction. The die profile function is given as:

$$x = y = F(z) = \frac{W+A}{2} + \frac{W-A}{2}\cos\left(\frac{\pi z}{L}\right) \quad \ldots \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \quad (7)$$

The die profile function satisfies the boundary condition such that at z=0, x=W and z=L, x=A. The exit and entry angles are non-zero angles. The velocity-discontinuity surfaces are normal to the axial flow directions.

3.3 Computation

An integrated FORTRAN code was developed to compute the upper bound extrusion load using Eq. (1).For any reduction R and friction factor m, the program first calculates the velocity components and the strain rate components using Eq. (4) and (5) respectively and then evaluates the upper-bound on power Eq.(1) by numerical integration using the 5-point Gauss-Legendre quadrature algorithm. The total power [22] of deformation has been minimized using a multivariable optimization technique.

CHAPTER 4

DIE PROFILE DESIGN

Die is very important part of extrusion assembly for extrusion of the materials.

4.1 Requirement of die preparation

The requirement for die material should be accurate, dimensionally stable, setting expansion and contraction; variations in response to change in temperature need to be minimum, strong and durable withstand the desire and finishing procedures economical and easy to use.

The different type of curved [29] dies used for extrusion of materials.

1) Cosine profile die
2) Convex circular profile die
3) Concave circular profile die
4) Convex elliptic profile die
5) Concave elliptic profile die
6) Convex parabolic profile die
7) Concave parabolic profile die
8) Convex hyperbolic profile die
9) Polynomial shaped profile die
10) Bezier shaped profile die

The different type of materials used for manufacturing of curve dies profiles.

1) Molybdenum high speed steel.
2) The various grades of tool steels.
3) Cemented carbides.
4) Steel bonded carbides.

Extrusion is of importance to all plastic processing. The required die profile to achieve the desired product dimensions is a very complex task and requires detailed knowledge of material properties and flow, heat transfer phenomena,. Extrusion die design is still more an art than a science, even though the latter is becoming more and more relevant for design optimization because of modern advancement in the powerful computation and modelling of complex flow and heat transfer processes, before, through, and after the die. The proper design of an extrusion die is extremely important to achieve the desired shape and accurate dimensions of the extruded product. In this chapter we derive an extrusion die profile for square section from square billet using cosine function. First of all a mathematical equation of the die profile is derived. Then using MATLAB the co-ordinate of the die profile is calculated. The generated co-ordinates were used in CATIA to generate solid model of the cosine die profile. The die geometry is shown in Fig. 3.1.

The Die-profile function is Eq. (7)

$$x = y = F(z) = \frac{W + A}{2} + \frac{W - A}{2} \cos\left(\frac{\pi z}{L}\right)$$

The die profile function F(z) is similar in both x and y direction. The die profile function satisfies the boundary condition such that at z=0, x=W and z=L, x=A. The exit and entry angles are non-zero angles. The velocity-discontinuity surfaces are normal to the axial flow directions.

Where W and A are the semi width of billet and product respectively and L is the die length.

In this chapter die design for 30%.60% and 90% reduction considered and cosine die profile Equation different for different- different % of reduction shown in equation (8-10).

4.2 For 30% Reduction Cosine Die profile equation

Here A_0=20×20 mm^2, A_f =16.7332×16.7332 mm^2 and L_0=40 mm

W=10mm and A= 8.3666 mm.

So $x=y=f(z)=9.18333+0.8167 \cos\left(\frac{z\pi}{L}\right)$ …… … … … …… … … …… .. (8)

4.3 For R= 60% reduction cosine die profile equation

Here A_0=20×20 mm^2, A_f =12.6491×12.6491 mm^2 and L_0 =40 mm

W=10mm and A= 6.3245 mm.

So $x=y=f(z)=8.16225+1.83775\cos\left(\frac{2\pi}{L}\right)$ …… …… …… … …… ….. (9)

4.4 For R= 90% Reduction Cosine Die profile equation

Here A_0=20×20 mm^2, A_f =6.3245×6.3245 mm^2 and L_0=40 mm

W=10mm and A= 3.16225 mm.

So $x = y = f(z) = 6.581125+3.418875\cos\left(\frac{2\pi}{L}\right)$ … …… …… …… …… … .. (10)

Table 4.1 the dimension of dies with different-different % of Reduction.

Si.No	% of Area Reduction	Input side (mm)	Input Area (mm^2)	Output side(mm)	Output Area (mm^2)	Height of Die (mm)
1	30	20	400	16.7332	279.9999822	40
2	60	20	400	12.6491	159.9997308	40
3	90	20	400	6.3245	39.99930025	40

4.5 Solid modeling

MATLAB was used to generate the no. of points using above generated die profile equation. The generated points were used to create solid model using CATIA. Solid model generated from CATIA were show in the following figures.

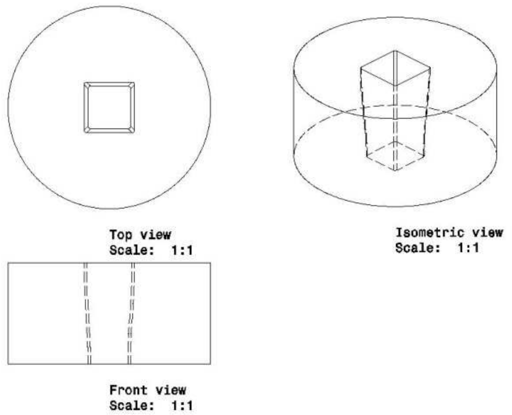


Fig. 4.1 The top view, bottom view and isothermal view for 30% reduction

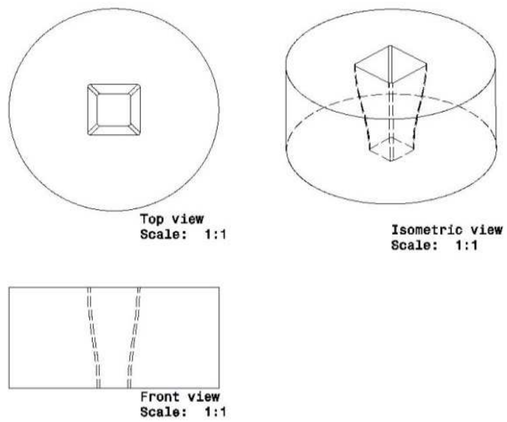


Fig. 4.2 The top view, bottom view and isothermal view for 60% Reduction

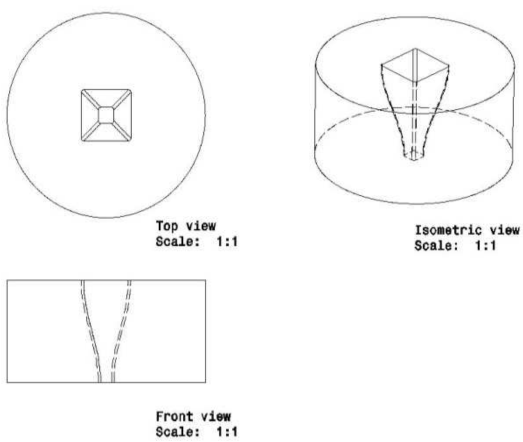


Fig. 4.3 The top view, bottom view and isothermal view for 90% Reduction

4.6 Design of an Experimental set-up for square to square Extrusion through cosine curved die (different-different % of Reduction) profile with dimension

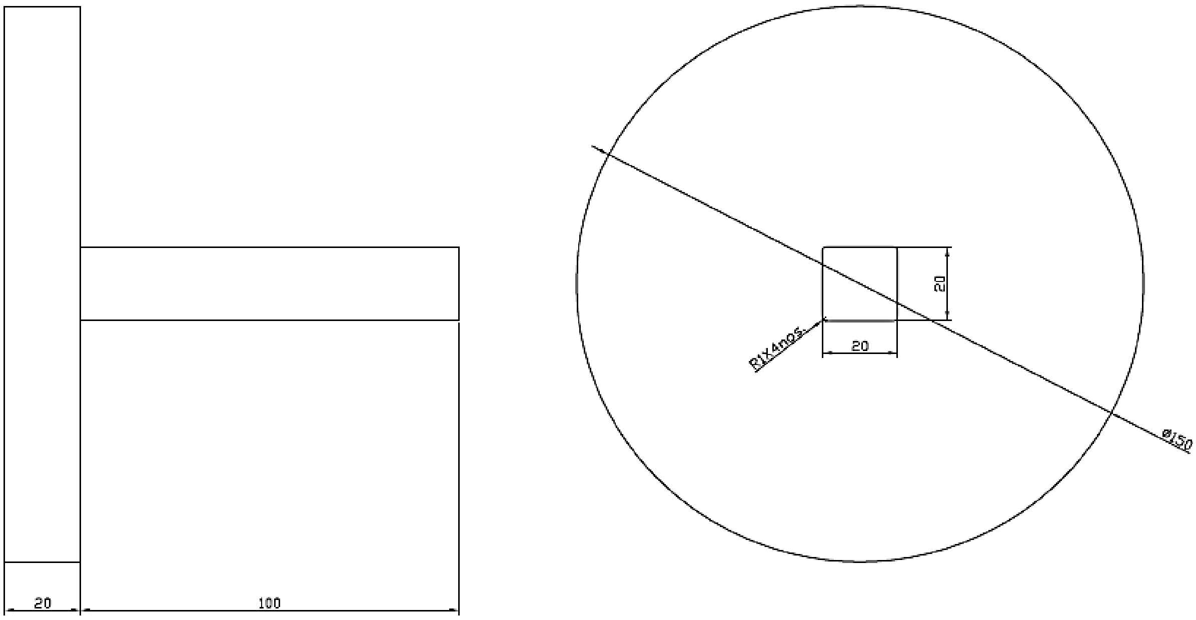


Fig. 4.4 Punch

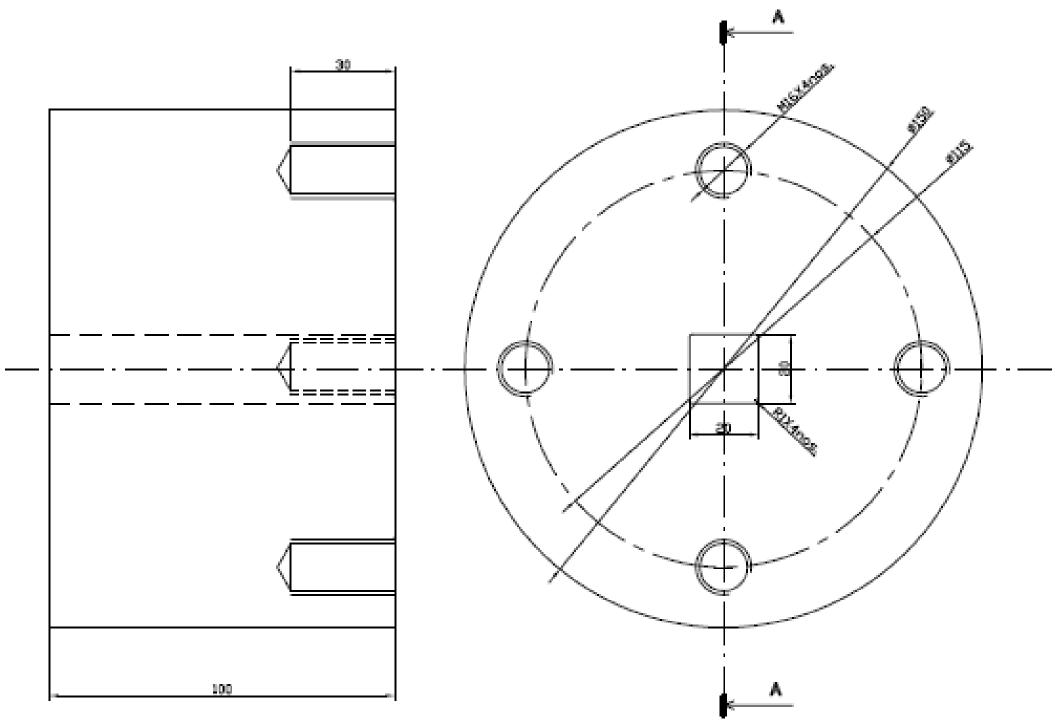


Fig. 4.5 Billet holder

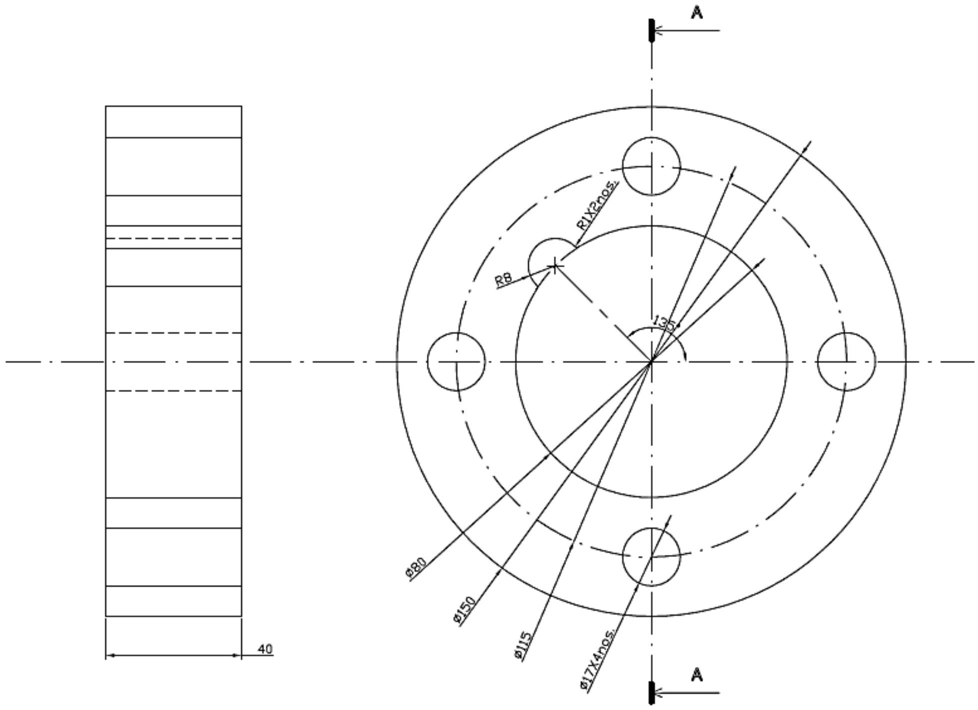


Fig. 4.6 Die holder

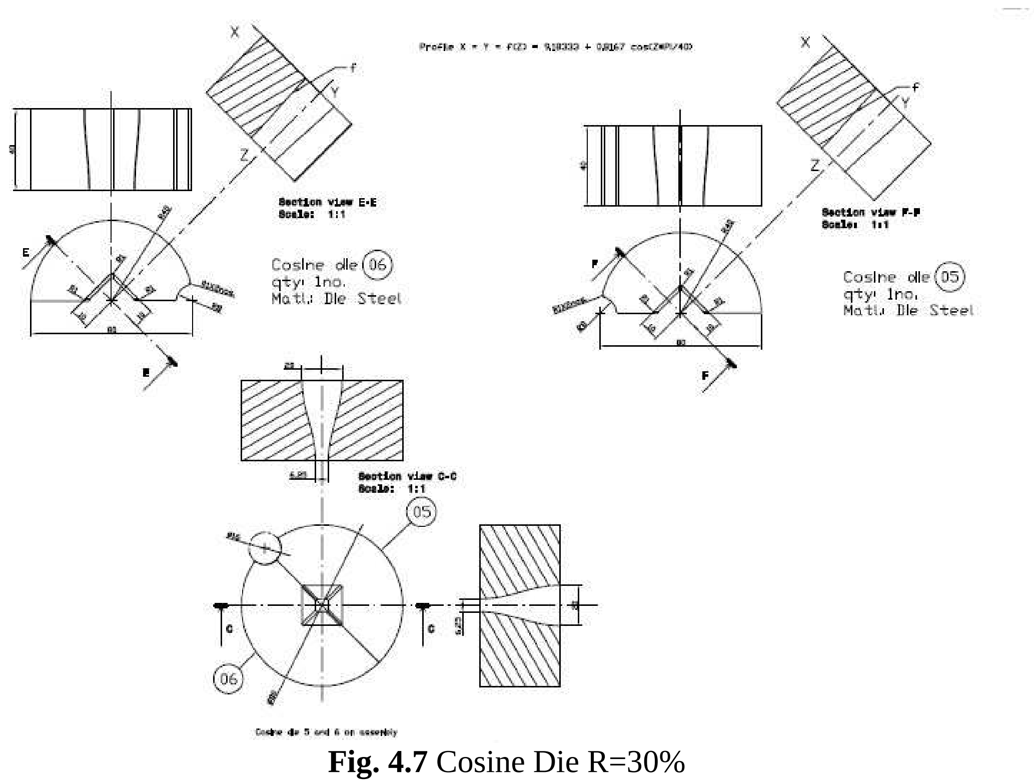


Fig. 4.7 Cosine Die R=30%

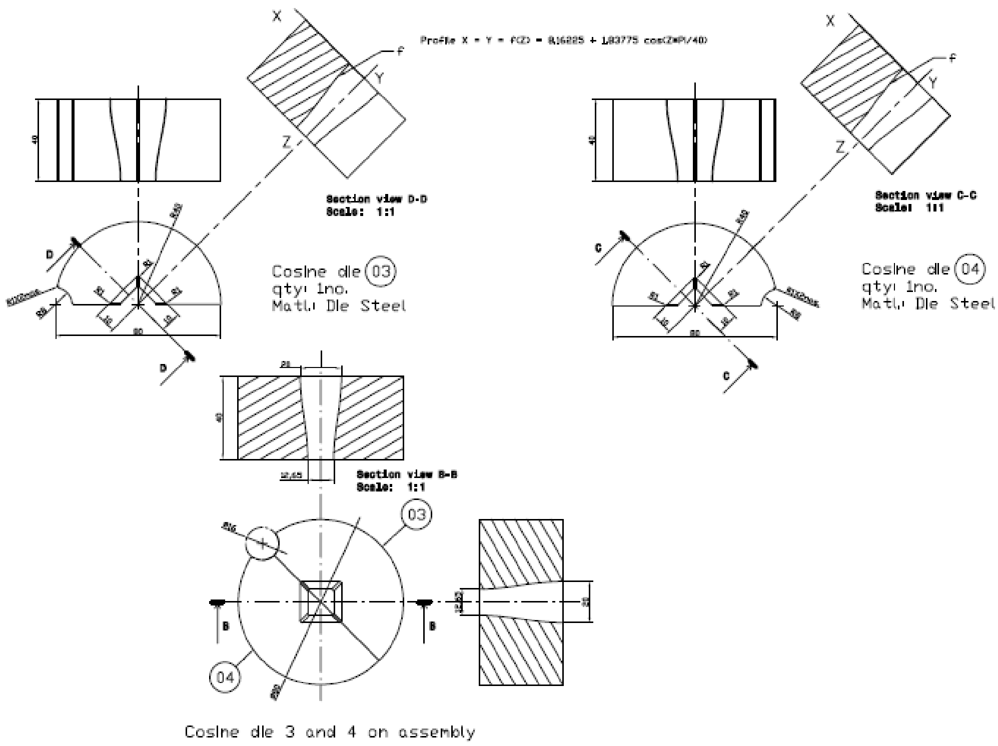


Fig.4.8 Cosine Die R=60%

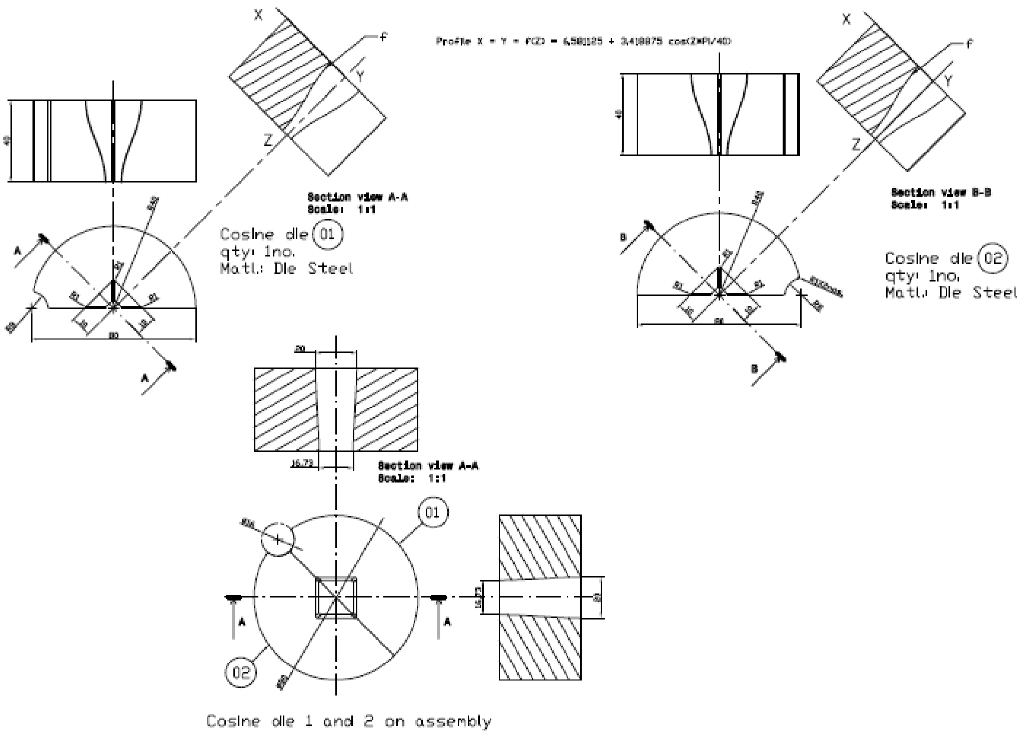


Fig. 4.9 Cosine Die R=90%

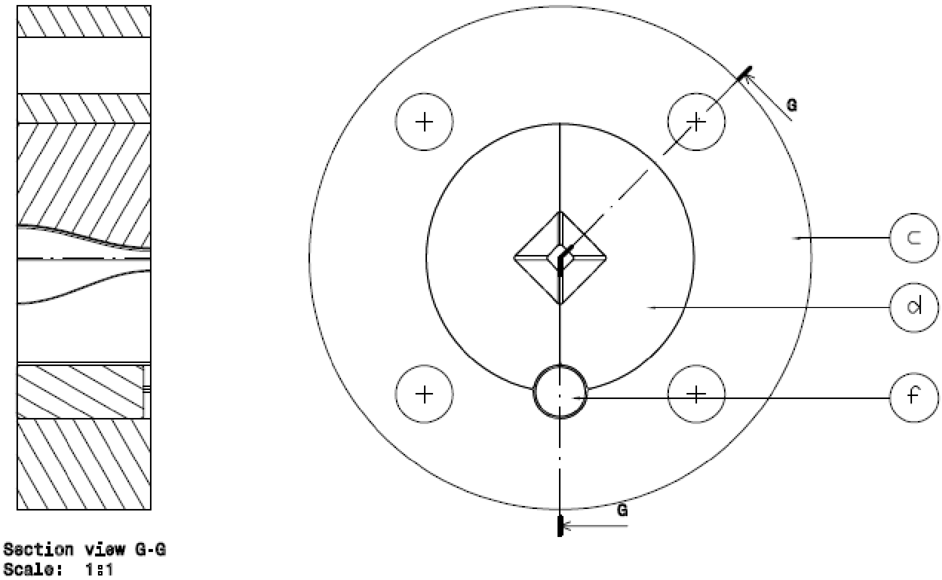


Fig. 4.10 Cosine Die Assembly

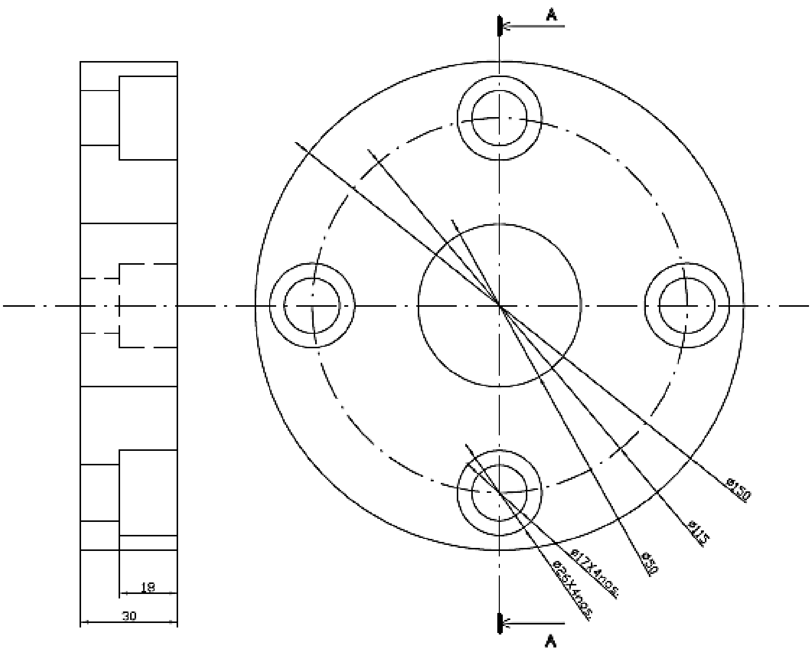
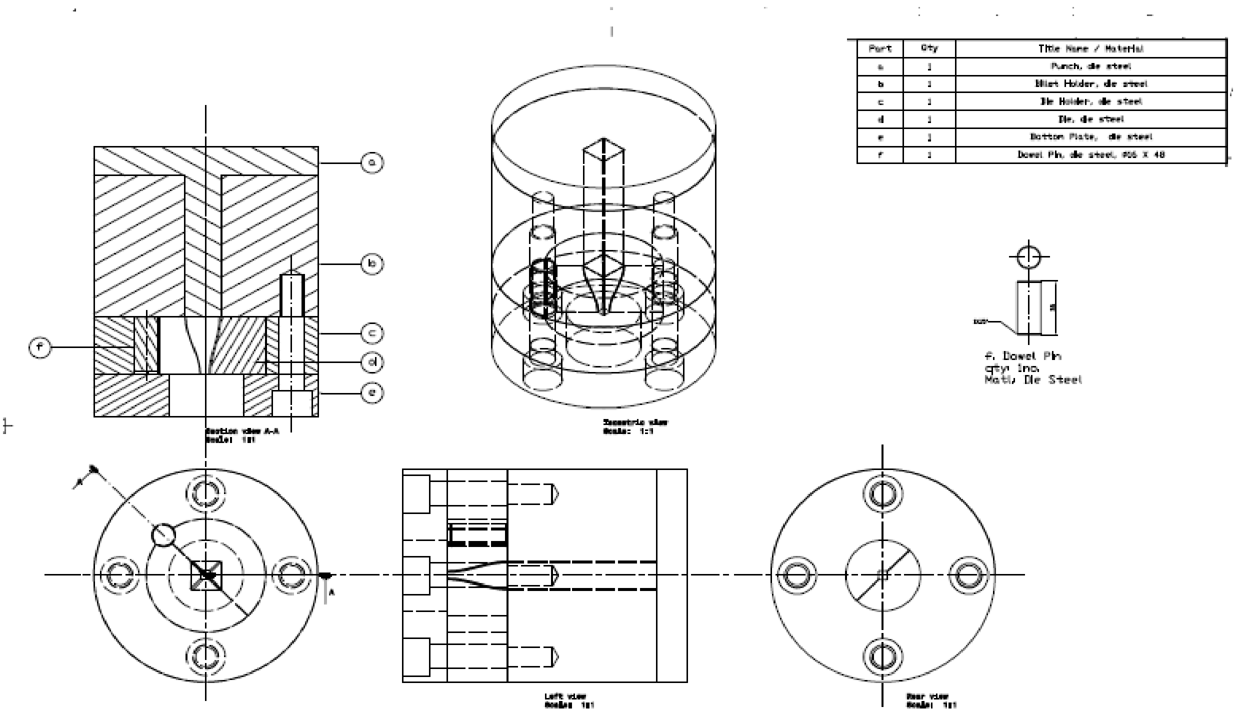


Fig. 4.11 Bottom Plate



Part	Qty	Title Name / Material
a	1	Punch, die steel
b	1	Billet Holder, die steel
c	1	Die Holder, die steel
d	1	Die, die steel
e	1	Bottom Plate, die steel
f	1	Dowel Pin, die steel, Ø06 X 48

Fig. 4.12 Cosine Die Assembly with Experimental set-up

4.7 Advantage of Die [31]

1) Very good toughness.
2) Excellent thermal conductivity.
3) High resistance to thermal shock.
4) Good hot oxidation resistance.
5) Wear resistance Excellent.
6) Softening resistance is very good.

4.8 Limitation of die [30]

1) Wear.
2) Stability of support tooling.
3) Formation of thermal fatigue cracks.
4) Plastic deformation and cracking.
5) Indentation.

CHAPTER 5

FINITE ELEMENT ANALYSIS

FEM modeling is a powerful technique used for different metal deformation problems including extrusion. In the present study, FEM modeling has been carried out for extrusion of square section from square billet with cosine Die profile, using DEFORM-3D software. Damage, effective strain (mm/mm), effective Strain rate ((mm/mm/sec)), effective stress (MPa), max principal stress (MPa), Total Velocity and Temperature (C°) distribution obtained during simulation process.

5.1 Finite element simulation

A FEM based program DEFORM-3D software which consists of three special features such as

1) Pre-processor
2) FEM simulation
3) Post-processor

The block diagram of simulation process in DEFORM-3D software is shown in fig. 5.1.

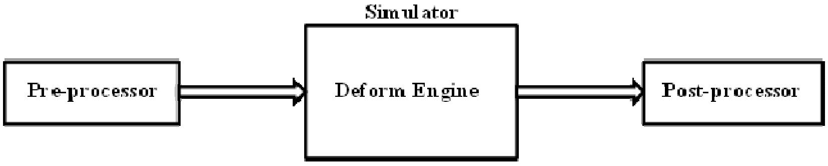


Fig. 5.1 Block Diagram of DEFORM-3D Software process

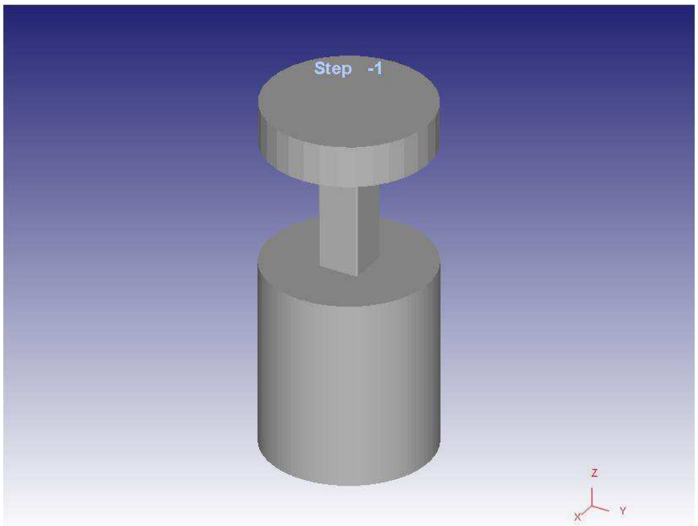


Fig. 5.2 Modelling of punch, billet, container and die used in DEFORM-3D Software

5.1.1 Block Pre-processing

In DEFORM 3-D Software for Creating a new problem first of all go to start button and select DEFORM-3D from the menu after that DEFORM-3D main window will appear in the screen then create a new problem by either selecting file new problem or by clicking the New Problem icon the problem setup window will appear Accept the default setting of opening a new problem using the DEFORM-3D pre-processor then click the next button to define the location of the new problem under problem home directory. In a simulation controls click a simulation control and rename a simulation Title, change unit SI and click OK. In Loading object data, if there is not an object currently defined in the object Tree add an object to the problem by clicking the insert object button at the bottom of tree. Change the object name to block and click change, Object type must be Plastic. After that go to Geometry → input geometry → select geometry check geometry → Ok. After that go to mesh generation to click the mesh button to bring up the Meshing Controls →Set the Number of Element then go to preview button →Generate mesh. In Display manipulation there various functions present the display window such a span, Zoom, Magnify, and rotate. In point Selection any point on an object in the display window can be selected to obtain the corresponding data for the point and also distances can be measured between two points on one objector between two points on different objects. In other display window icons there are various icons present in this window such a view fit, capture image print view shaded mesh etc. after that to save the data by clicking save icon or select file →save. The information will be saved in a file called Block.KEY. Effective stress due to Von- Mises criterion

$$\sigma = \sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2}{2}} \qquad \ldots\ldots\ldots\ldots\ldots (11)$$

Where, σ_1, σ_2 and σ_3 are the principal stresses, $\sigma = \sigma_f$ is the flow stress in uniaxial Compression

Effective strain rate,

$$\varepsilon = \frac{\varepsilon_1(\sigma_1-\sigma_m)+\varepsilon_2(\sigma_2-\sigma_m)+\varepsilon_3(\sigma_3-\sigma_m)}{\sqrt{\frac{3}{2}\{(\sigma_1-\sigma_m)^2+(\sigma_2-\sigma_m)^2+(\sigma_3-\sigma_m)^2\}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. (12)$$

Where ε_1, ε_2 *and* ε_3 are the principal strain rate and σ_m= hydrostatic stress

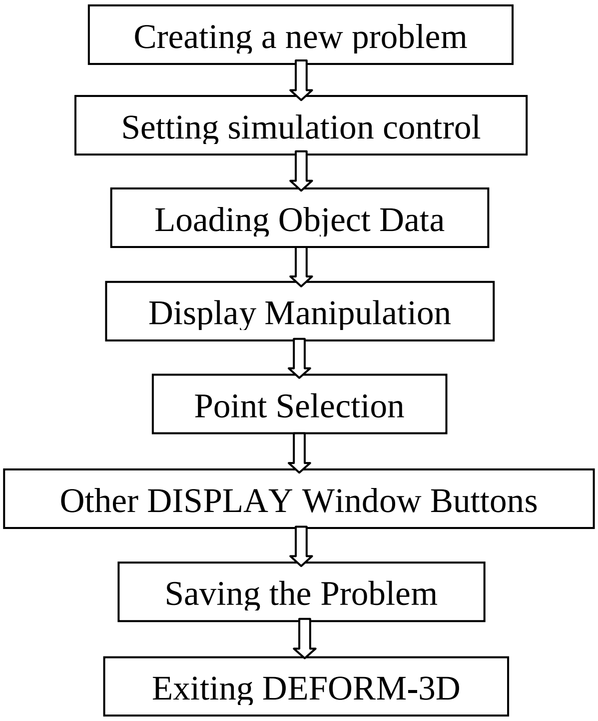


Fig. 5.3 Block diagram of Pre-Processing

5.1.2 Block Die positioning and Pre-Processing

In this process open a previously saved problem click DEFORM-3D.Pre to enter the Pre-processor. After that to importing a workpiece, then insert object tree to odd Top Die (punch) and Bottom Die (Die with container).after that select TOP Die → Geometry →Import Geometry→check Geometry and click to OK. Select the bottom Die in Object Tree then go to General and change Object name→change→ Geometry →import Geometry → Select Geometry → Check Geometry →Ok. In Setting Die movement click the top die in the Object Tree since this is the Objects that will be moving, it should be designated as the Primary Die. This is done by going to the general [30] section and placing a checkmark next to primary Die. To define the movement click movement button the die will be moving downward at a constant Speed 1mm/sec.(late) In setting object temperature the material properties such as Flow stress are defined as a function of temperature, so even though temperature is not changing in this simulation the work piece temperature should be specified correctly. The objects are first inserted into the Object Tree. In setting material properties, when setting up a simulation, material properties have to be specified for the objects the work piece has been assigned as plastic, click the material icon to bring up the material window. The workpiece in this simulation needs to be defined as Al-6062 (good machining properties). To import this material click the load from lib.button and then select the material from list. In setting simulation controls, click the Simulation Control icon to open the simulation control window. Click step to view the time step controls. And given starting step number (-1) and (100) and step increment. And click OK. In object positioning, open the object positioning window by clicking icon. The various positioning method available within DEFORM-3D are Drag, Drop, offset, Interference, Rotational etc. In inter-object Relationships, click the inter object icon to define the relationship between the objects. And go to edit then deformation →friction factor →value→ constant→cold forming (carbide Die 0.08) then close. Click to add a new relation →master die (Top Die) →slave Die (Bottom Die) →apply to the other relations →Generate all →Ok. In Generating a Database, once the problem has been completely set up, the last step is to generate a database file. The FEM engine (calculates the solution) uses a database file to store the finite element solutions for the problem. When you generate a database in the DEFORM Pre-processor all the information defined in the Pre-processor (such as the material properties movement controls, object geometries etc.) is transferred to the database file. Click on database generation button to open database generation window. Click the check button to have the program check to see if anything was missed in the problem setup. During the checking progress→ Generate →close. After that saving the problem, the database for the problem (Block DB) was just generated, which is needed to run a simulation. By clicking the save icon a keyword file called Block. KEY will be saved. Click exit to return to main window.

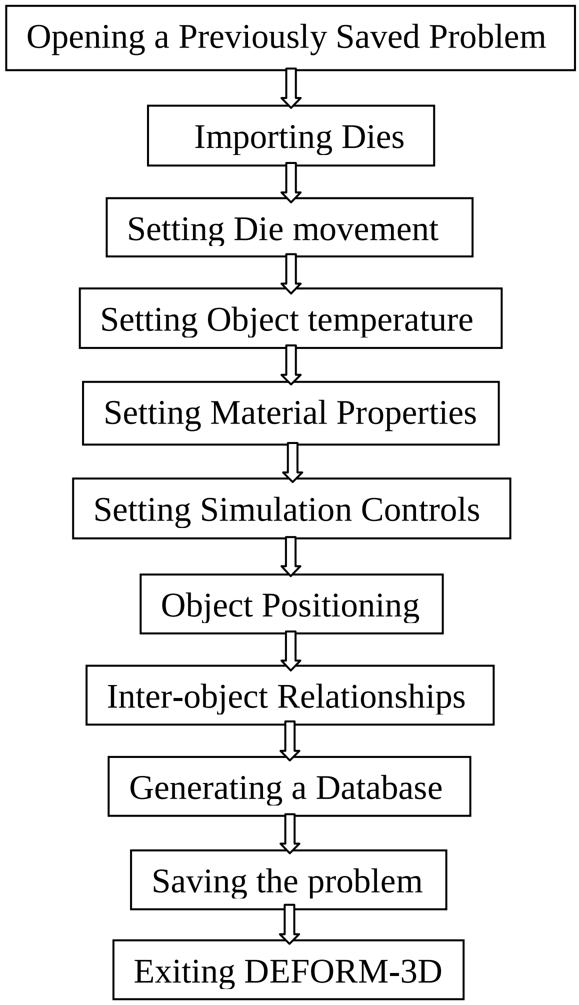


Fig. 5.4 Block Diagram of Die positioning and Pre-Processing

5.1.3 Block forging simulation and post-processing.

Opening a previously saved problem in this process if deform is not already open, open it as you did in the previous lab. When the main window opens, Click on the BLOCK folder in the Directory list and then highlight the BLOCK .DB file in the file list. After that start the simulation by clicking Run in the simulator list. When simulation has finished the following message will be added to the end of the message file. NORMAL STOP, the assigned step have been completed. In post processing the results, after the simulation has completed, click DEFORM-3D Post under Post processor. In post processing the result optioned by step selection, state variables (like, damage, Strain-Effective, Strain Rate–Effective, Stress-Effective, Stress-Max. Principal, Velocity-Total, Temperature etc.), In point tracking to open the point tracking window by click the icon, and sea the graph with point Tracking. In slicing Objects by clicking the icon to open the slicing window, the object can be sliced in several different ways. When you are finished. Exit the post-processor by clicking the Exit icon when you back in the main window, exit DEFORM-3D by clicking exit icon.

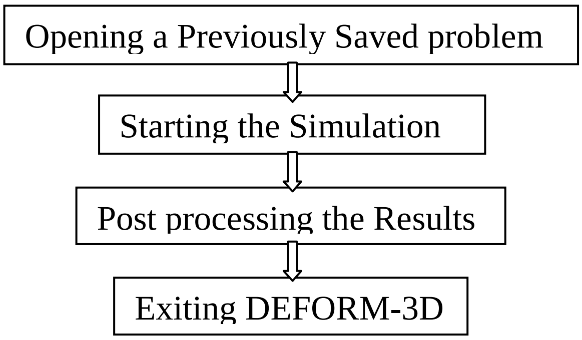


Fig. 5.5 Block Diagram of Forging simulation and post-processing

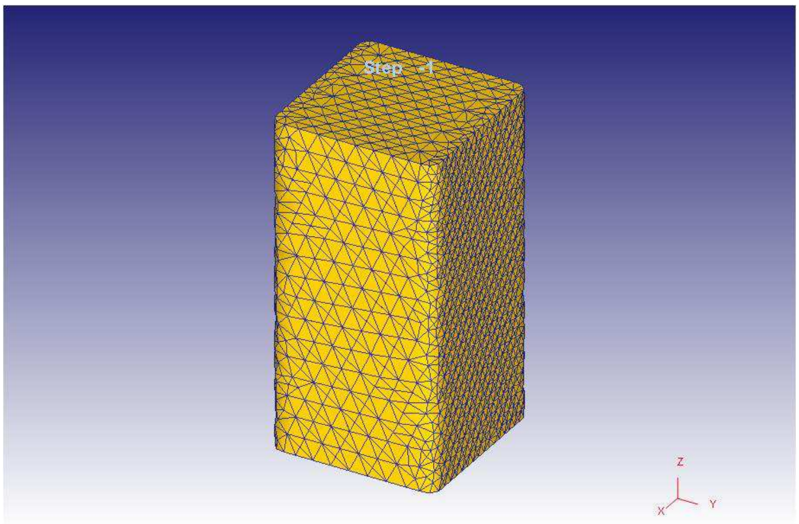


Fig. 5.6 Mess formulation for square billet (Size Ratio=1; Number of elements =25000)

5.2 The simulation results by FEM analysis for cosine die profile (A_0=20×20 mm^2 and L_0=40mm)

From the present modelling, The Damage, effective strain, effective strain rate, effective stress, max. Principal stress, total velocity and temperature distribution for cosine die profile are analysed for different reductions. The rigid plastic material (Al-6062) is assumed in the model. At the entry plane, the total billet velocity is equal to the punch velocity, (1mm/sec.) where as it is equal to the product velocity at the exit plane. The product velocity is predetermined from volume constancy condition. The operation was carried out at room temperature. After the FEM simulation, the state Variables and the variation of extrusion load with respect to ram travel for 30%, 60%, 90% Reduction is indicate in Fig. (5.7-5.21) with constant friction factor (m=0.38). This deformation process is taking an isothermal process. The Fig. (5.7-5.10) show the state variables for 30% reductions and Fig. 5.11 indicate the relation between Load (N) and Stroke (mm) during Extrusion process the maximum load optioned during Deformation Process around 51000N or 51kN. The Fig. (5.12-5.15) indicates the state variables for 60% Reduction and Fig. 5.16 indicate a relation between Load (N) and stroke (mm) during Extrusion Process, the maximum load optioned during Deformation Process around 116000 or 116kN.

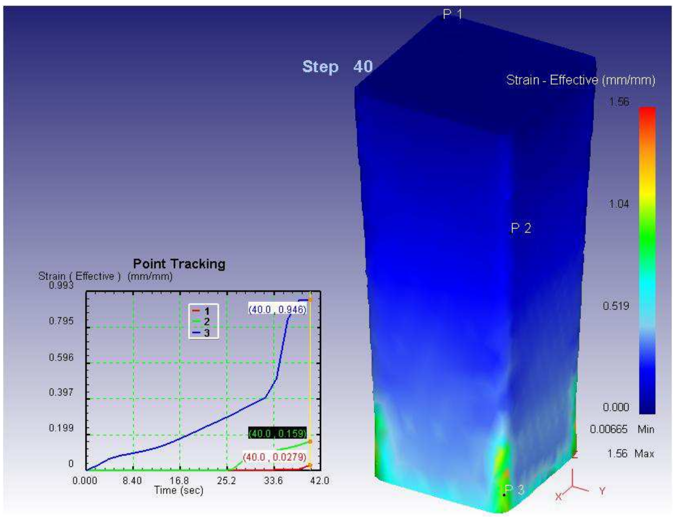


Fig. 5.7 Strain-Effective with point Tracking (30%)

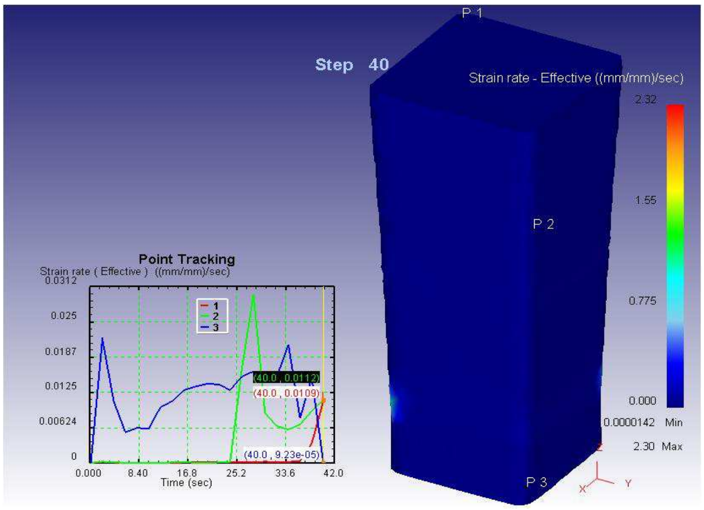


Fig. 5.8 Strain Rate –Effective with Point Tracking (30%)

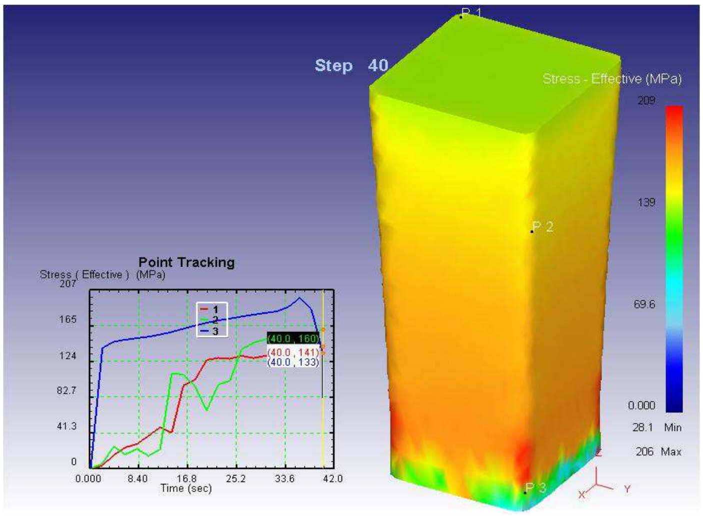


Fig. 5.9 Stress-Effective with Point Tracking (30%)

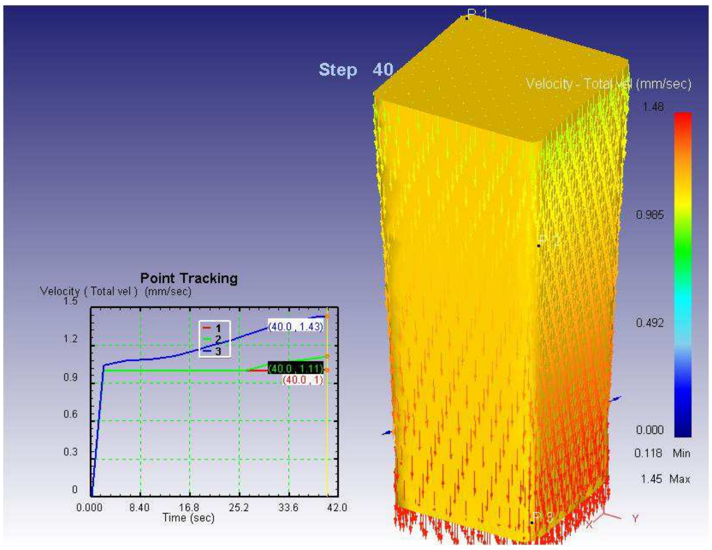


Fig. 5.10 Velocity–Total Velocity with Point Tracking (30%)

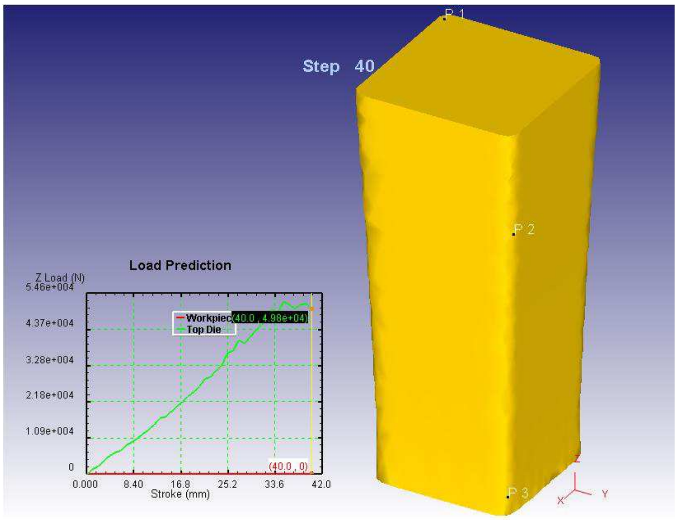


Fig. 5.11 Load vs. Stroke with point Tracking (30%)

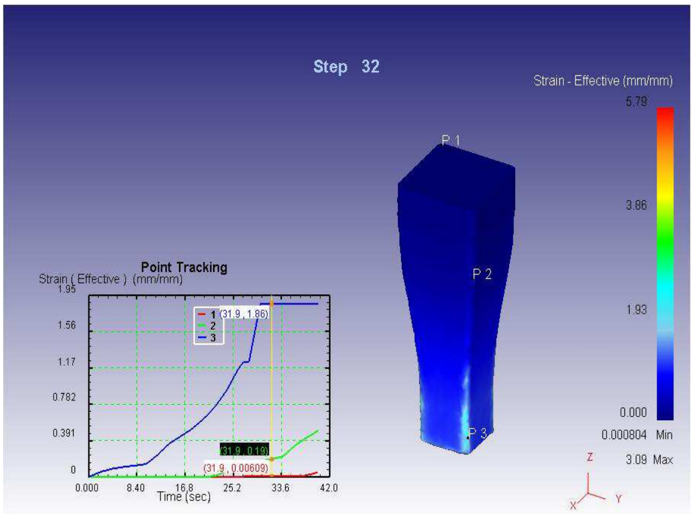


Fig. 5.12 Strain-Effective with point Tracking (60%)

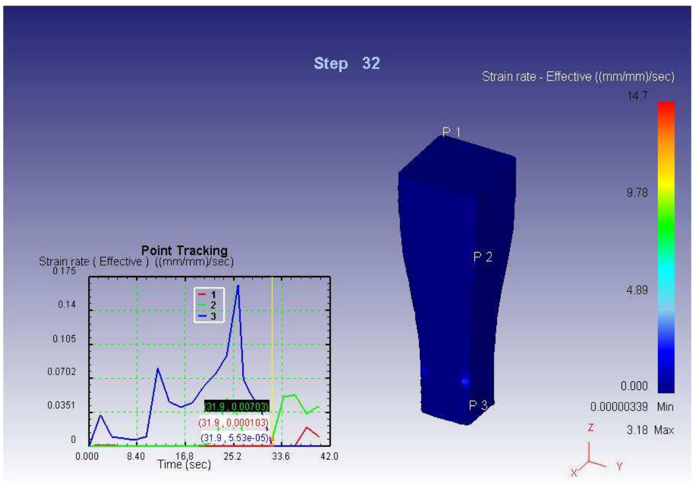


Fig. 5.13 Strain Rate-Effective with point Tracking (60%)

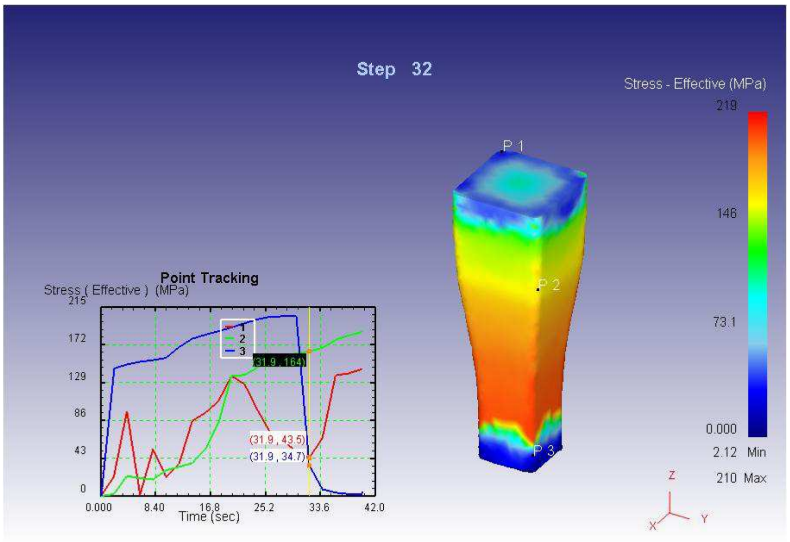


Fig. 5.14 Stress-effective with Point Tracking (60%)

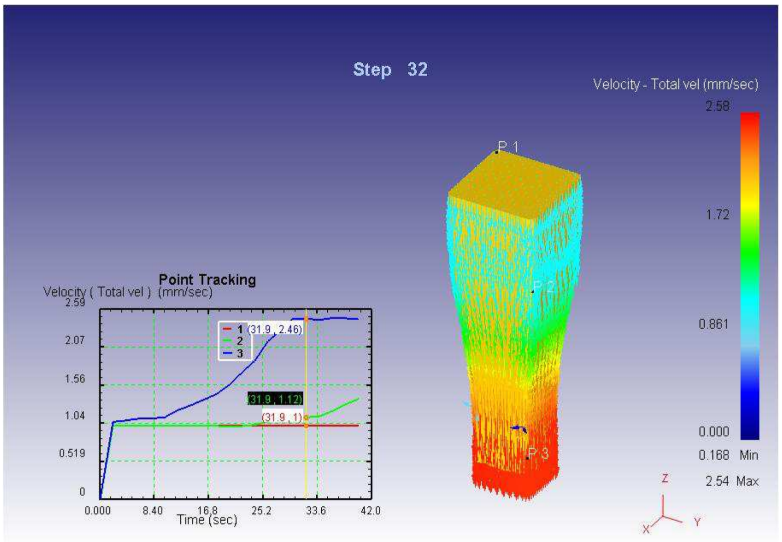


Fig. 5.15 Velocity –Total Vel (60%)

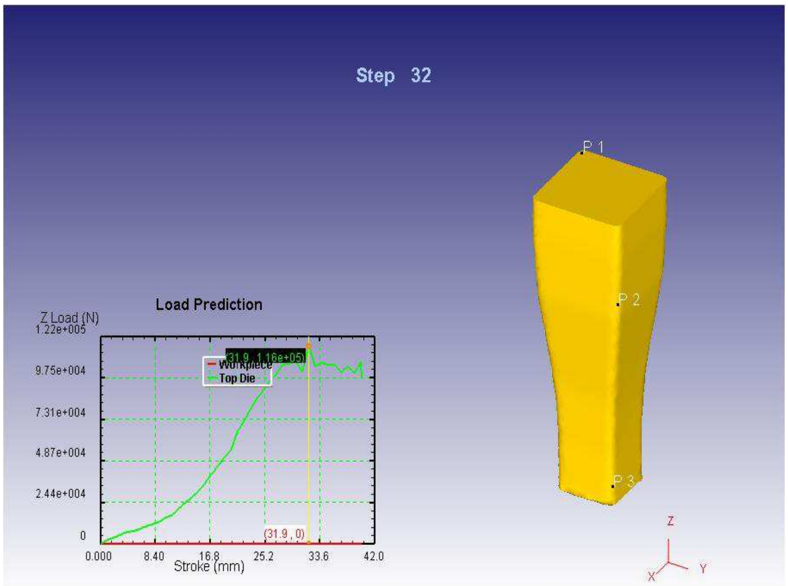


Fig. 5.16 Load v/s Stroke with Point Tracking (60%)

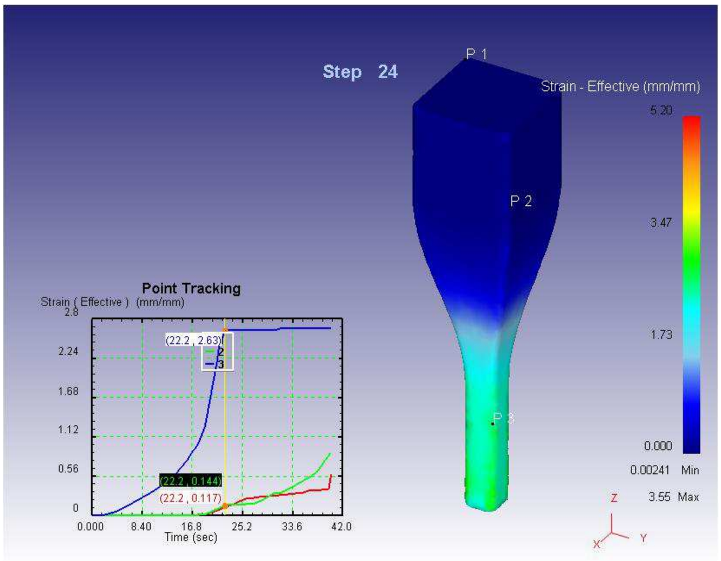


Fig. 5.17 Strain-effective with point Tracking (90%)

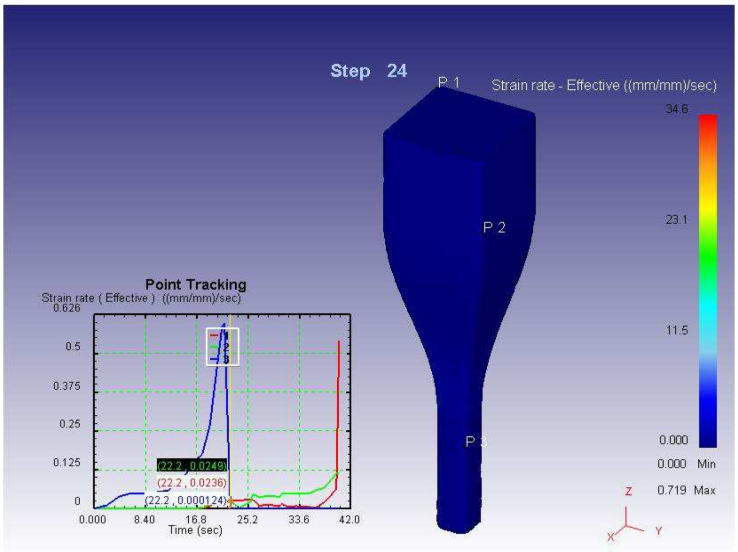


Fig. 5.18 Strain Rate –Effective with Point Tracking (90%)

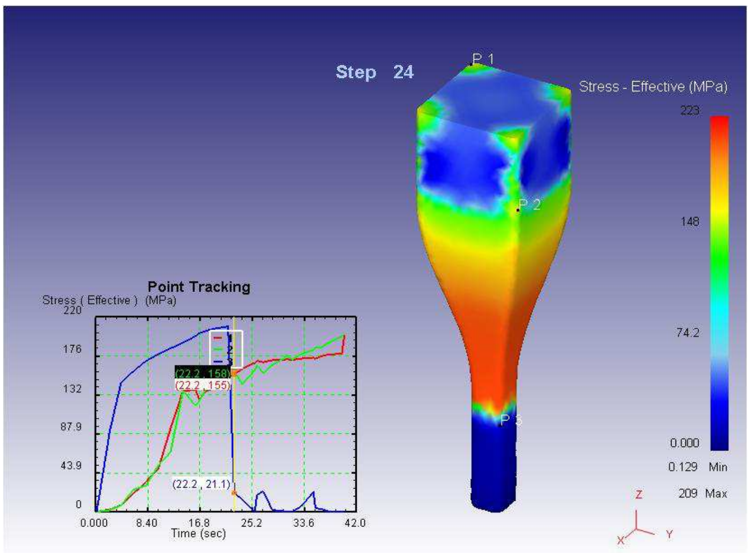


Fig. 5.19 Stress-Effective with Point Tracking (90%)

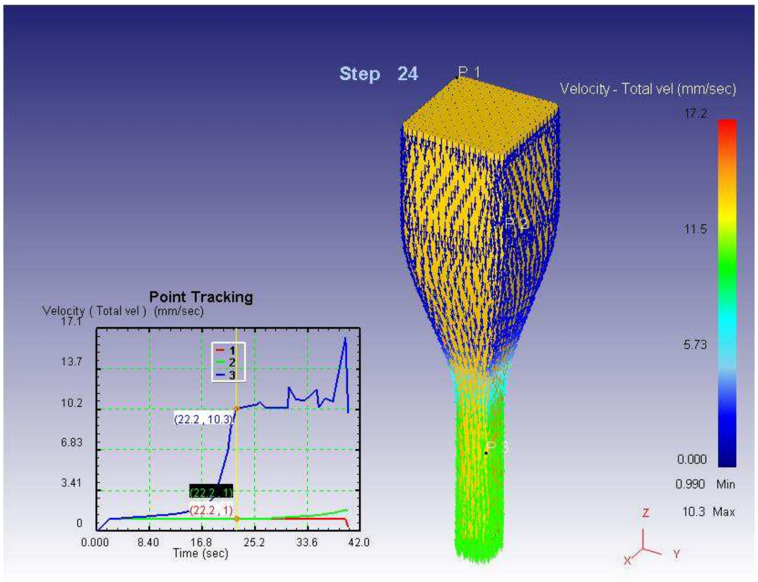


Fig. 5.20 Velocity-Total (90%)

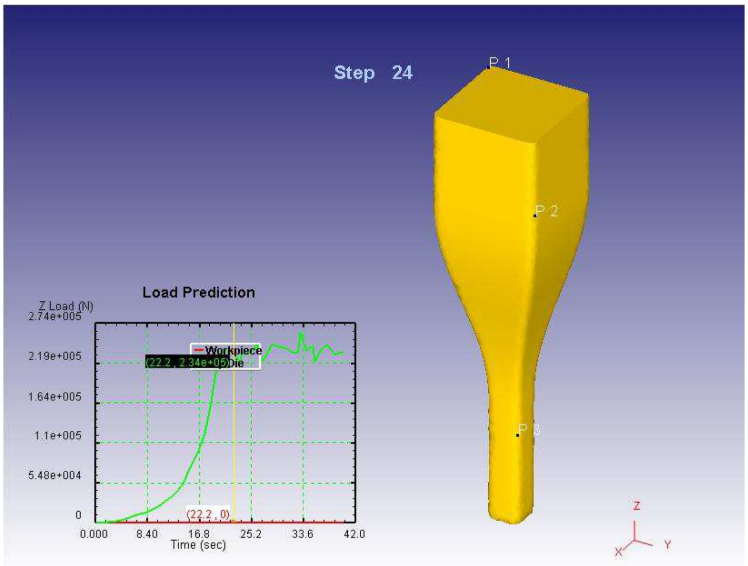


Fig. 5.21 Load vs. Stroke with Point Tracking (90%)

The Fig. (5.17-5.20) indicates the state variables for 90% Reduction and Fig. 5.21.indicate a relation between Load (N) and stroke (mm) during Extrusion Process, the maximum load optioned during Deformation Process around 261000 or 261kN

5.3 The simulation results by FEM analysis for cosine die profile (A_0=40×40mm^{2}and L_0=60mm)

From the present modelling, The Damage, effective strain, effective strain rate, effective stress, max. Principal stress, total velocity and temperature distribution for cosine die profile are analysed for different reductions. The rigid plastic material (Al-6062) is assumed in the model. At the entry plane, the total billet velocity is equal to the punch velocity (1mm/sec.), where as it is equal to the product velocity at the exit plane. The product velocity is predetermined from volume constancy condition. The operation was carried out at room temperature. After the FEM simulation, the state Variables and the variation of extrusion load with respect to ram travel for 30%, 60%, 90% Reduction is indicate in Fig. (5.22-5.36) with constant friction factor (m=0.38). This deformation process is taking a isothermal process. The Fig (5.22-5.25) show the state variables for 30% reductions and Fig. 5.26.indicate the relation between Load (N) and Stroke (mm) during Extrusion process the maximum load optioned during Deformation Process around 314000 or 314kN. The Fig. (5.27-5.30) indicates the state variables for 60% Reduction and Fig. 5.31.indicate a relation between Load (N) and stroke (mm) during Extrusion Process, the maximum load optioned during Deformation Process around 634000 or 634kN.

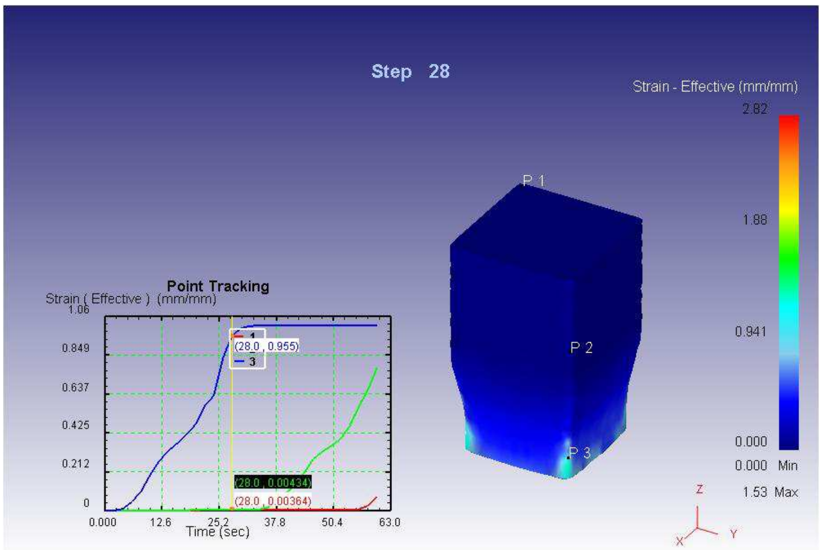


Fig. 5.22 Strain Effective with Point Tracking (30%)

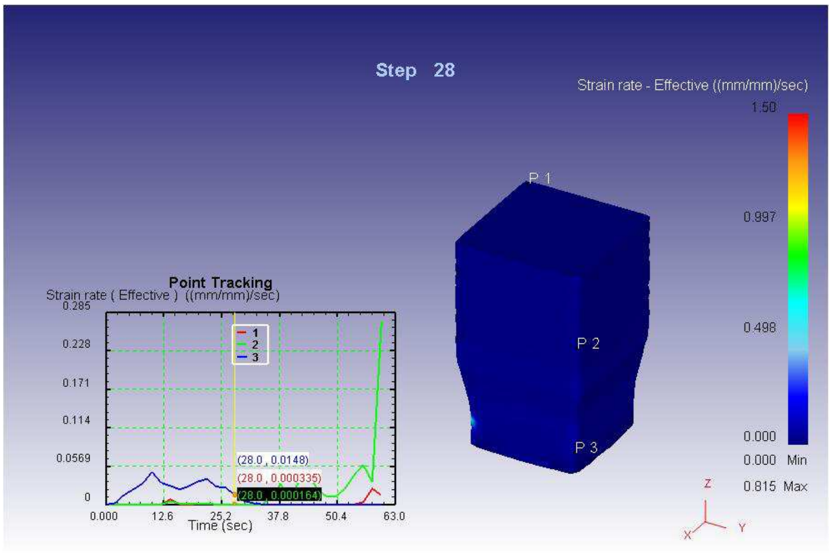


Fig. 5.23 Strain Rate-Effective with Point Tracking (30%)

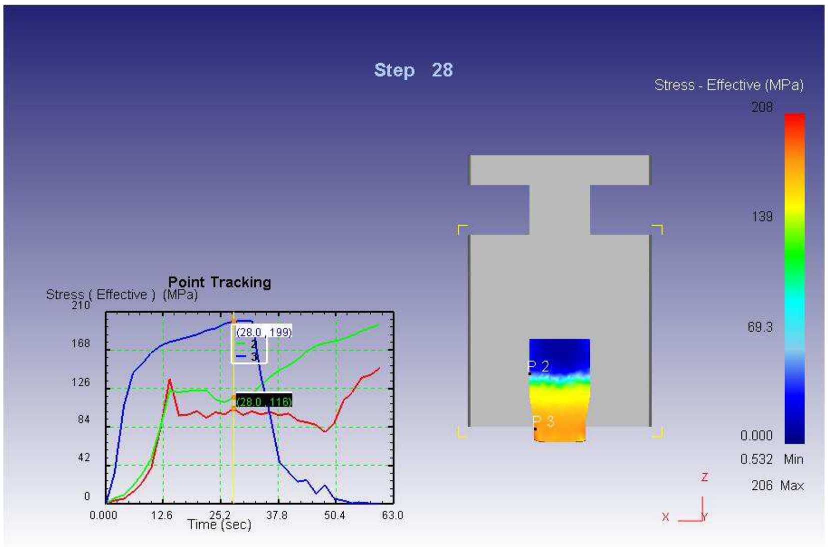


Fig. 5.24 Stress-Effective, Point Tracking and Slicing (30%)

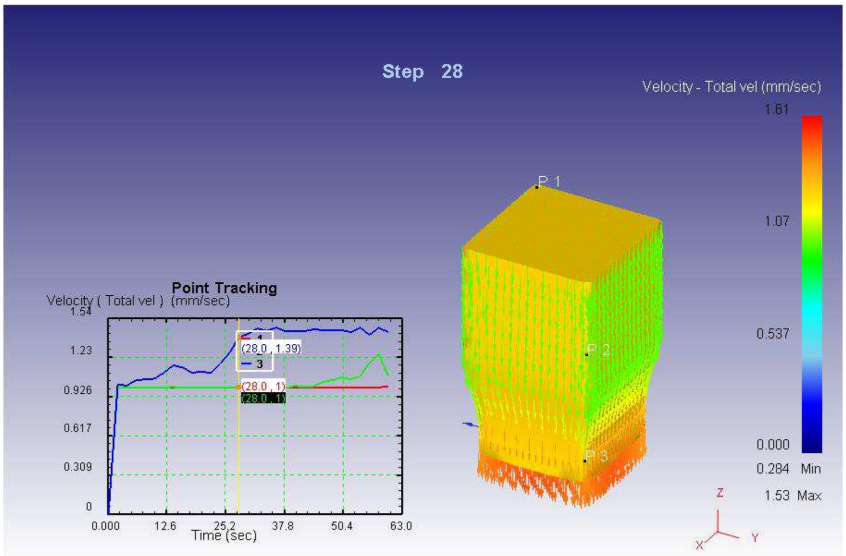


Fig. 5.25 Velocity-Total with point tracking (30%)

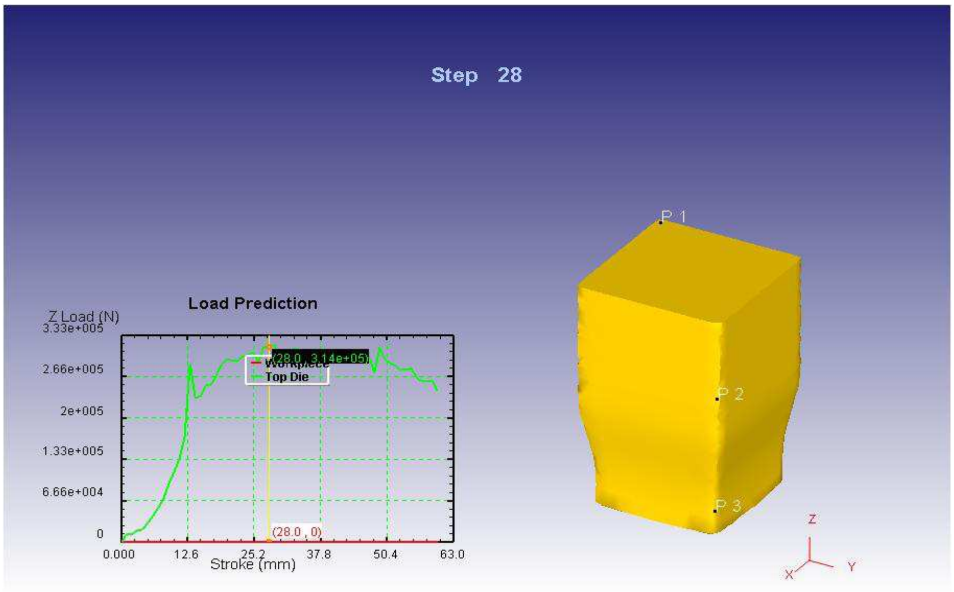


Fig. 5.26 Load vs. Stroke (30%)

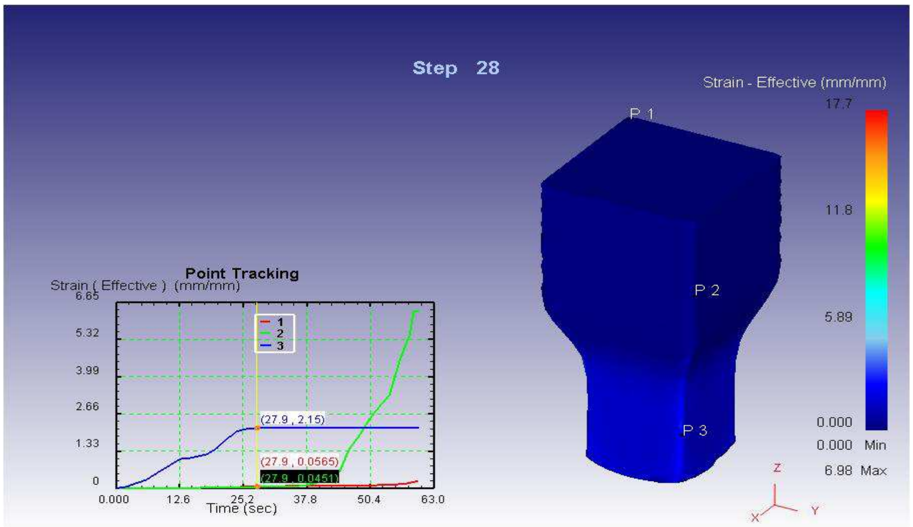


Fig. 5.27 Strain-Effective with Point Tracking (60%)

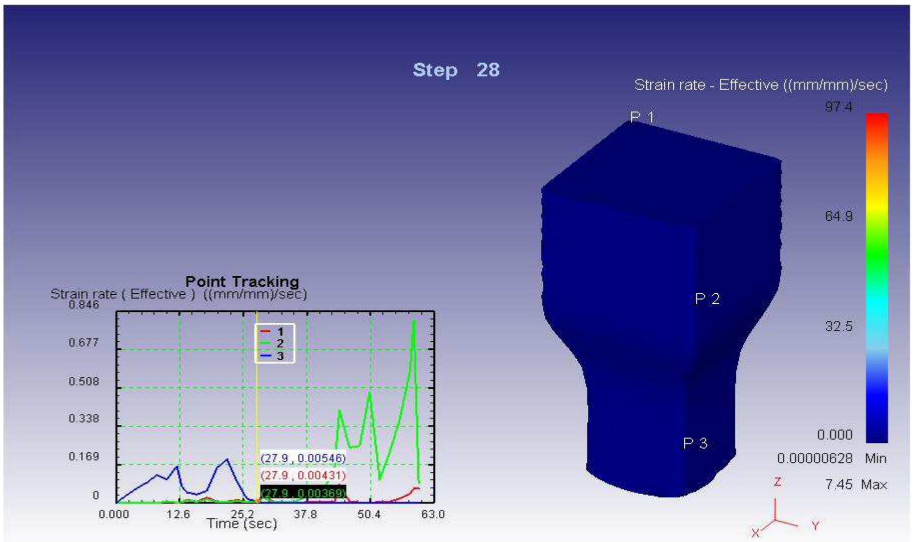


Fig. 5.28 Strain Rate-Effective with Point Tracking (60%)

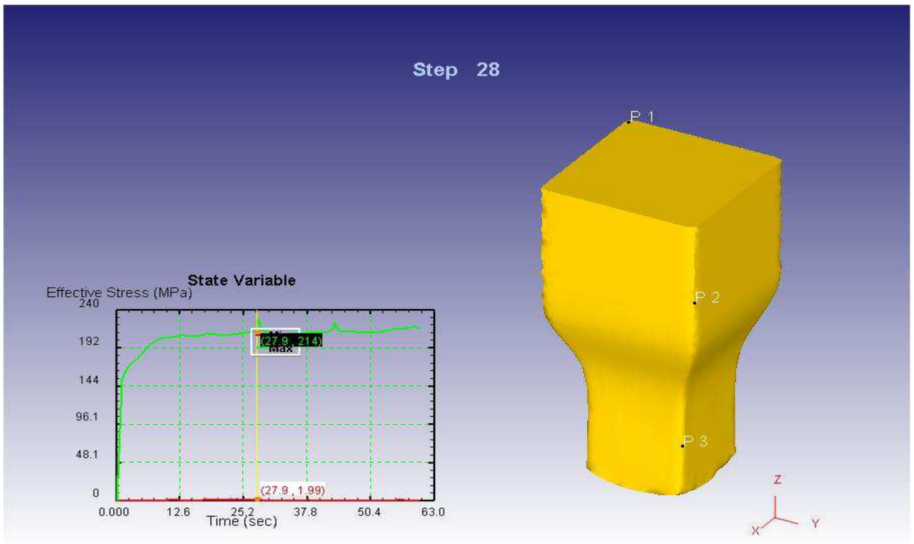


Fig. 5.29 Effective-Stress (60%)

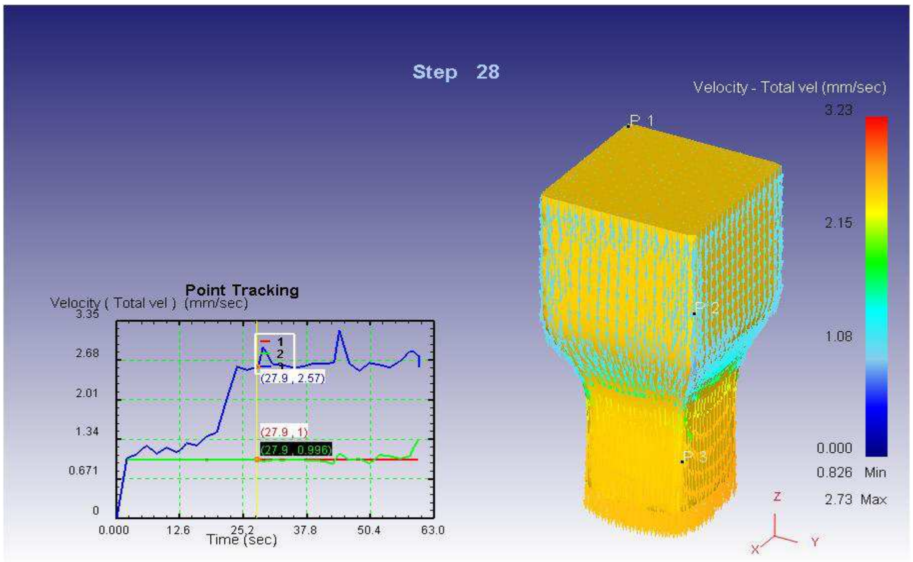


Fig. 5.30 Velocity-Total (60%)

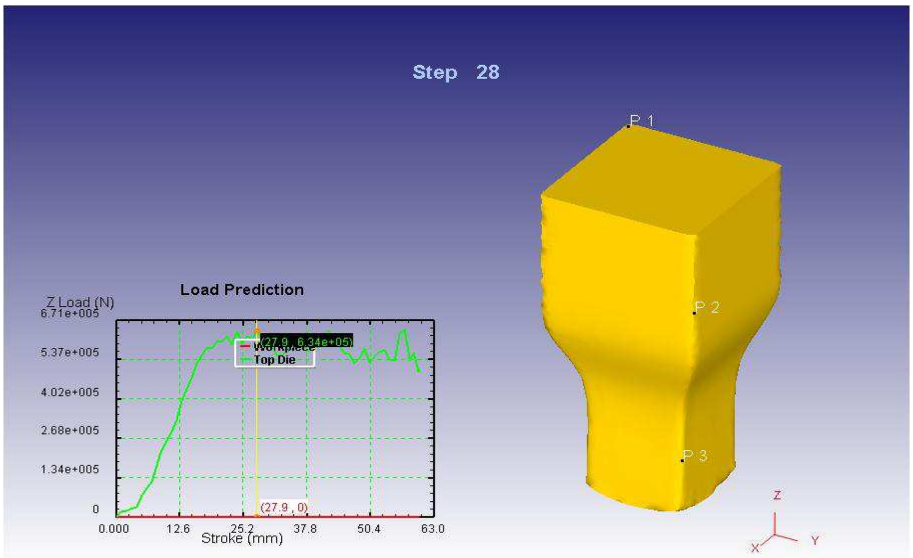


Fig. 5.31 Load vs. Stroke (60%)

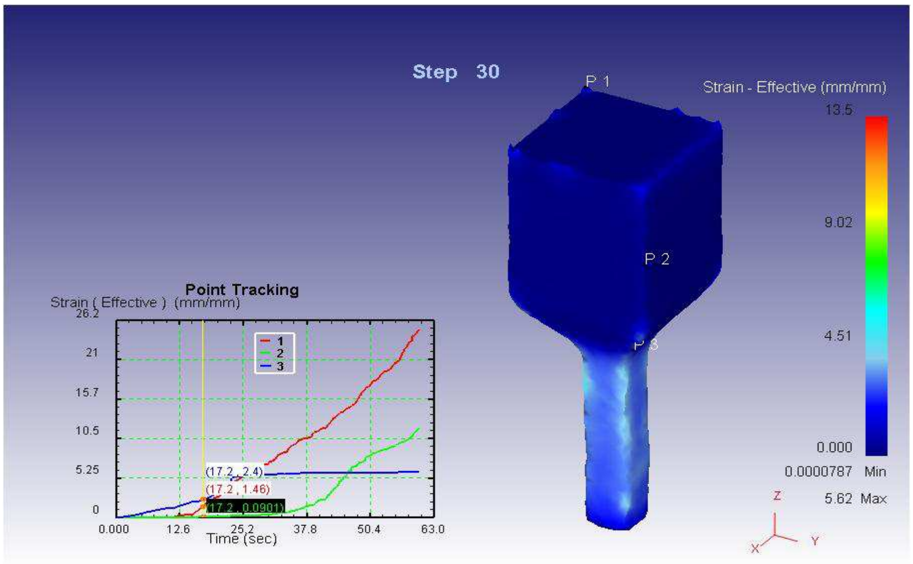


Fig. 5.32 Strain-Effective with Point-Tracking (90%)

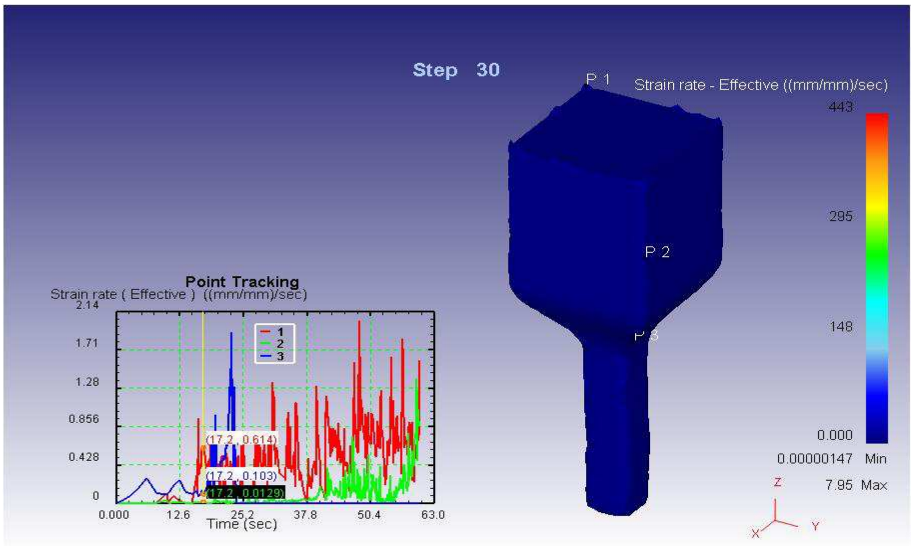


Fig. 5.33 Strain Rate-Effective with Point-Tracking (90%)

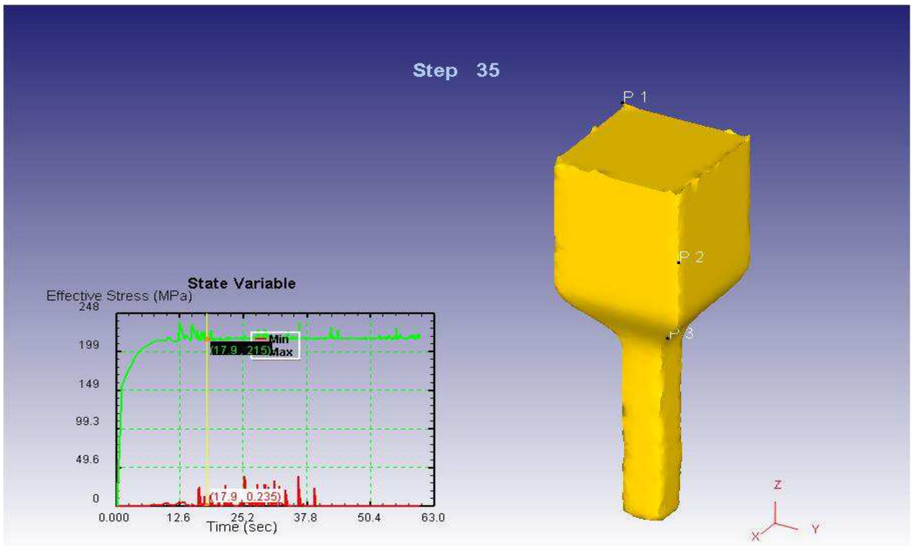


Fig. 5.34 Effective Stress (90%)

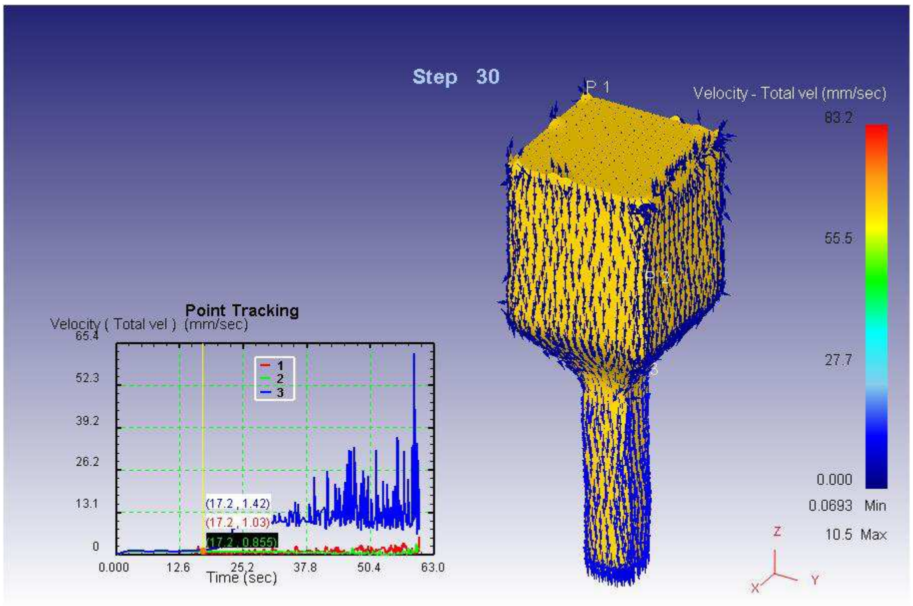


Fig. 5.35 Velocity-Total with Point Tracking (90%)

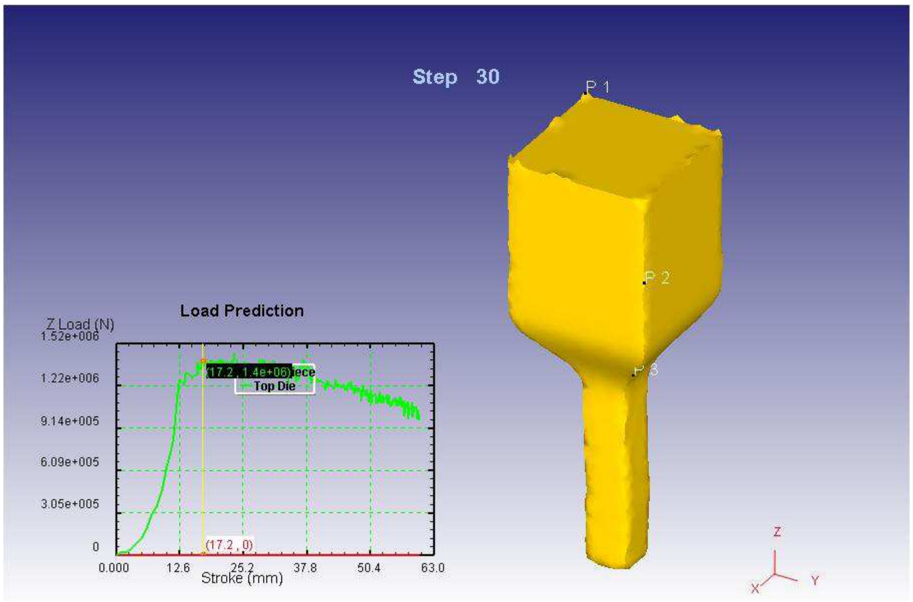


Fig. 5.36 Load vs. Stroke (90%)

The Fig. (5.32-5.35) indicates the state variables for 90% Reduction and Fig. 5.36 indicate a relation between Load (N) and stroke (mm) during Extrusion Process, the maximum load optioned during Deformation Process around 1450000 or 1450kN.

CHAPTER 6

RESULTS AND DISCUSSIONS

In this chapter all the results of FEM analysis are discussed. Results in different Reduction conditions are compared. The results of FEM analysis (Al-6062) are also compared with the results [29] of FEM analysis (Tellurium lead) form different-different % of Reduction values.

6.1 FEM Analysis Results (Al-6062) with initial cross-sectional Area (A_0 =20×20 mm^2 and L_0 = 40 mm).

The variation of extrusion load with respect to Stroke in wet condition is shown in the Fig. 6.1. The Fig. shows that the extrusion load increases with increase in percentage reduction. During extrusion process extrusion load gradually increases with increase in reduction and then becomes steady. It is also clear that initially, the load is almost same for all Reduction.

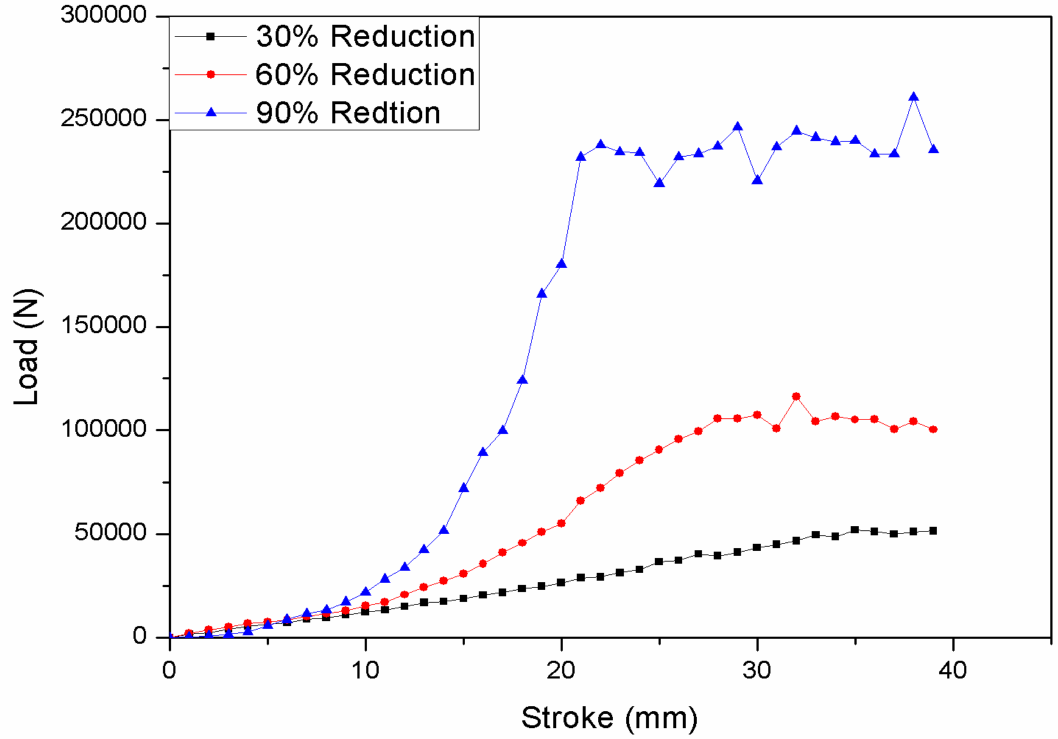


Fig. 6.1 Load vs. Stroke with 30%, 60% & 90% Reduction (FEA)

The variations of extrusion pressure with respect to % of reductions are shown in Fig. 6.2. For lubricated condition (m=0.38). The Fig. shows that extrusion pressure increases with increase in % of reduction during Extrusion Process.

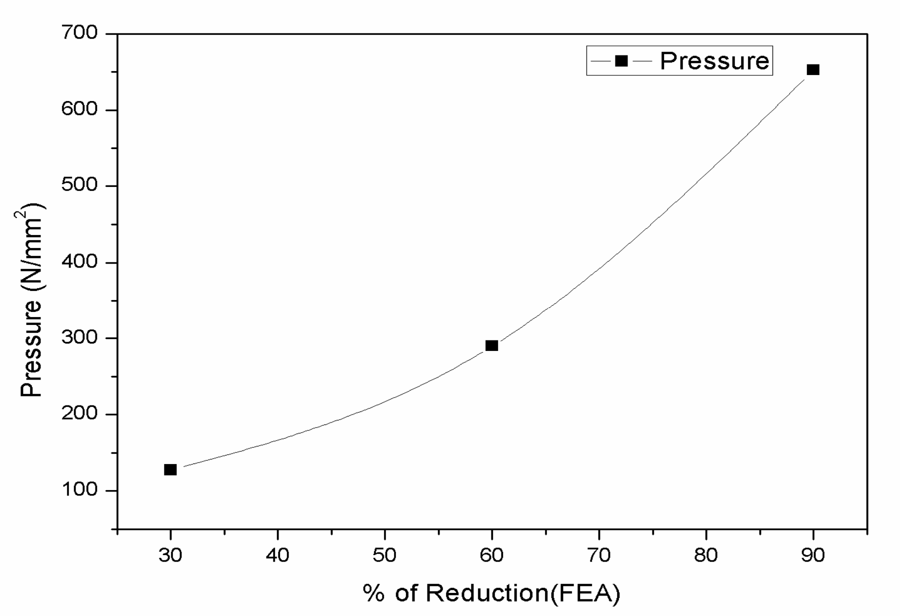


Fig. 6.2 Pressure vs. % of Reduction

6.2 FEM Analysis Results (Al-6062) with initial cross-sectional Area (A_0 =40×40mm^{2}and L_0= 60 mm)

The variation of extrusion load with respect to Stroke in wet condition is shown in the Fig. 6.3. The Fig. shows that the extrusion load increases with increase in percentage reduction. During extrusion process extrusion load gradually increases with increase in reduction and then becomes steady. It is also clear that initially, the load is almost same for all Reduction.

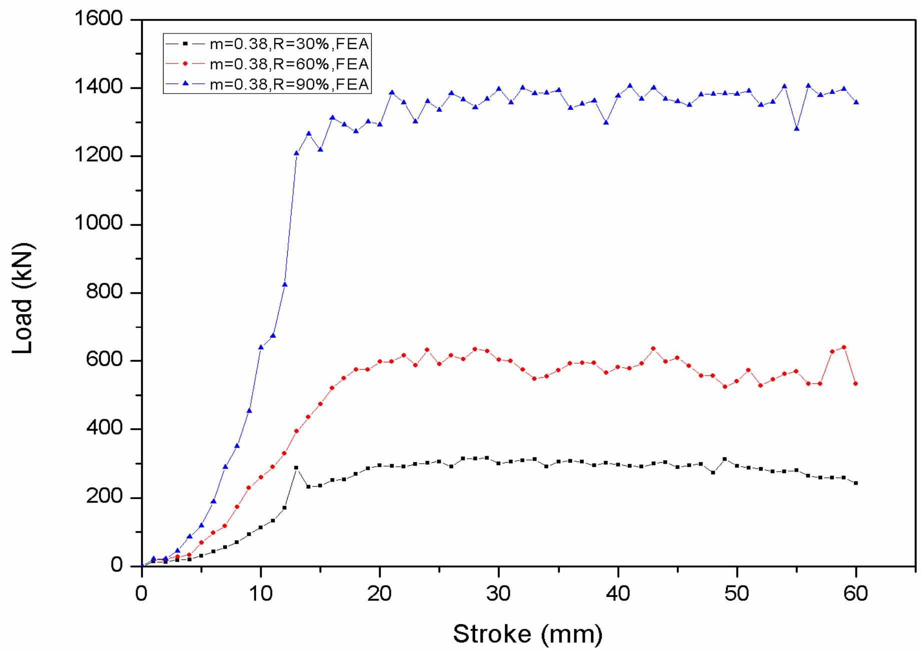


Fig. 6.3 Load vs. Stroke with 30%, 60% & 90% Reduction (FEA)

The variations of extrusion pressure with respect to reductions are shown in Fig. 6.4. For lubricated condition (m=0.38). The Fig shows that extrusion pressure increases with increase in % of reduction during Extrusion Process.

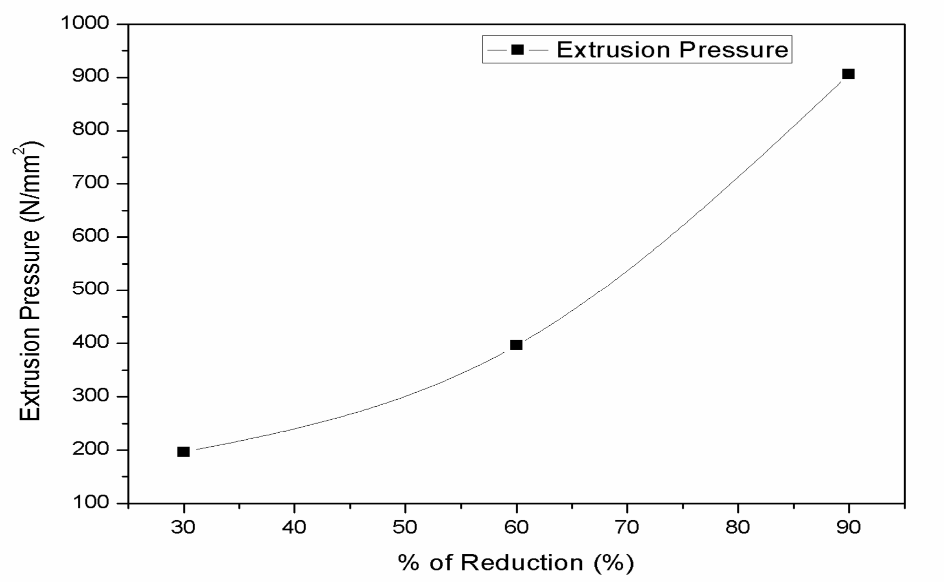


Fig. 6.4 Pressure vs. % of Reduction

6.3 FEM Analysis Results (Tellurium lead) with initial cross-sectional Area (A_0 =40×40mm^2 and L_0 = 60 mm).

The variation of extrusion load with respect to punch travel for 30%, 60% and 90% reductions is shown in Fig. 6.5 in lubricated condition (m=0.38). The extrusion load gradually increases and then becomes steady.

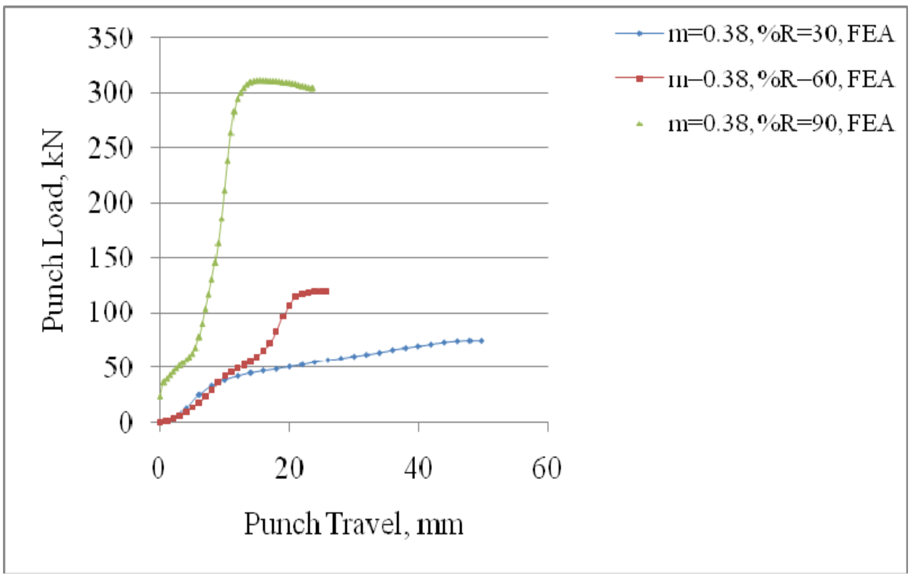


Fig. 6.5 Punch load vs. Punch travel for wet condition

The variation of extrusion pressure with respect to % of reductions is shown in Fig. 6.6 for lubricated condition (m=0.38). The figure show that the extrusion pressure increases with increase in reduction.

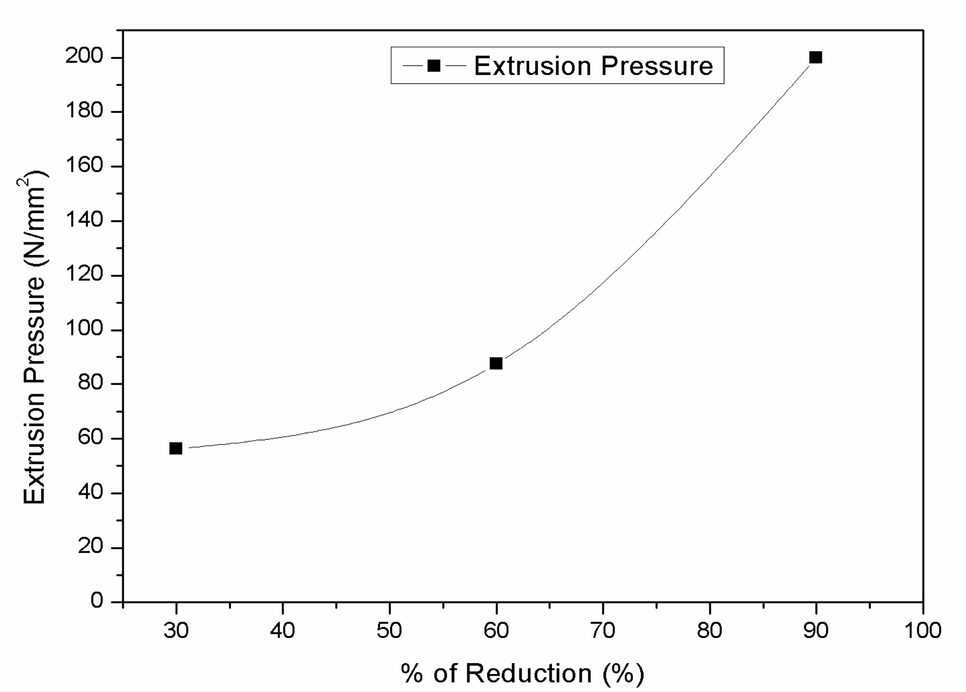


Fig. 6.6 Extrusion pressure vs. percent reduction (FEM)

6.4 Comparison between FEM Analysis Results [29] (Tellurium lead) with initial cross-sectional Area (A_0 =40×40mm^2 and L_0 = 60 mm) and FEA Analysis Results (Al-6062) with initial cross sectional Area (A_0 =40×40mm^2 and L_0 = 60 mm)

The FEM Analysis Results of Tellurium lead and Al-6062 is show in Table No. 6.1. It is clear that from the table the extrusion load and pressure of tellurium lead for square to square extrusion for different–different % of reductions from the cosine die profile are less as compared for Al-6062 from same % of reductions of square to square extrusion process. That means the load and presser required for AL-6062 extrusion are more as compared to tellurium lead for same % of reductions in extrusion process. Where Area of The Extrusion Chamber = 1600 mm^2.

Table 6.1 Results of Tellurium Lead [FEA] and AL-6062[FEA] material During Extrusion Process in DEFORM-3D Software

Reduction	Tellurium lead [FEA]		Al-6062 [FEA]	
(%)	Load (kN)	P (N/mm^2)	Load (kN)	P (N/mm^2)
30	90	56.25	314	196.25
60	140	87.5	634	396.25
90	320	200	1450	906.25

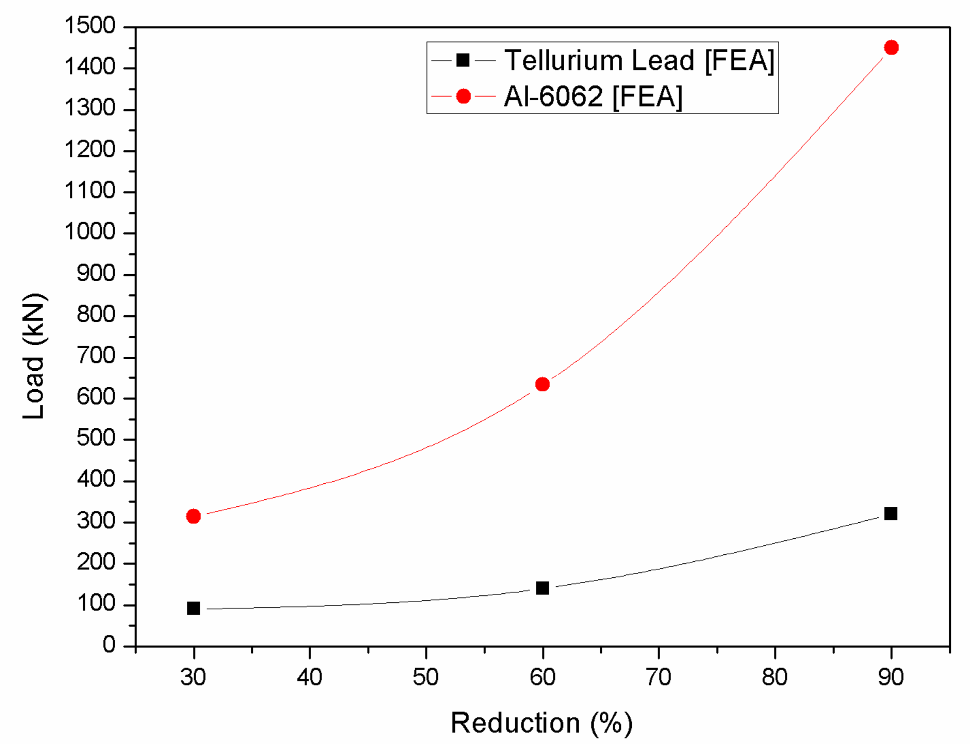


Fig. 6.7 Extrusion Load of Tellurium Lead and Al-6062

The variation of extrusion load with respect to Percentage of Reduction for 30%, 60% and 90% reductions is shown in Fig. 6.7 in lubricated condition (m=0.38). The Fig. shows that the extrusion loads of Al-6062 are more than the extrusion of Tellurium Lead for same percentage Reductions.

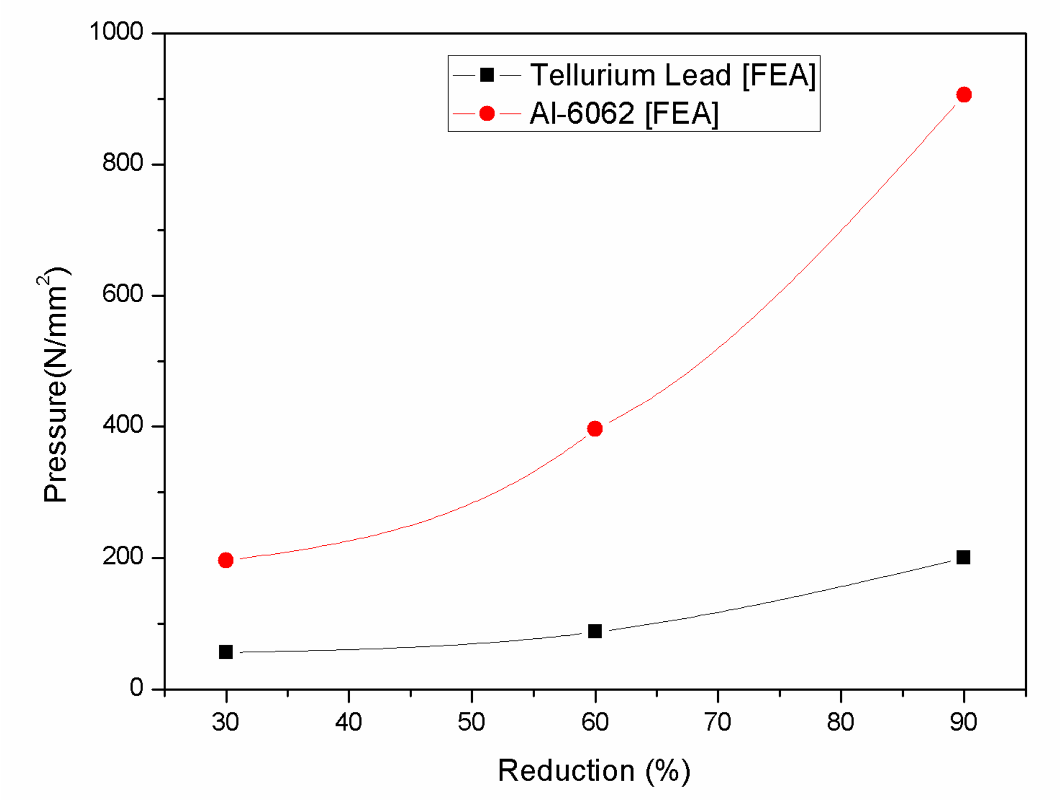


Fig. 6.8 Extrusion Pressure of Tellurium Lead and Al-6062

The variation of extrusion pressure with respect to % of reductions is shown in Fig. 6.8. For lubricated condition (m=0.38). The figure show that the extrusion pressure increases with increase in reduction and the Extrusion Pressure of Al-6062 is more than the extrusion of Tellurium Lead for same percentage Reductions.

CHAPTER 7

CONCLUSIONS

- ✓ A non-linear converging die profile has been designed for extrusion of square section from square billet using cosine profile function.
- ✓ The extrusion load and pressure increases with increase in reduction.
- ✓ The extrusion load for non-linear converging die is less as compared to linear converging die under same simulation condition.
- ✓ The flow of material in non-linear (Cosine) converging die appears to be gradual mainly in higher reduction.
- ✓ The effect of friction is more predominant in high reduction.
- ✓ A die profile function has been developed for extrusion of square section from square billet using a mathematically contoured die profile. The procedure can also be used to develop other die profiles.
- ✓ Solid CAD models of curved die profiles have been developed for extrusion of square section.
- ✓ FEM modeling has been carried out for extrusions of square section from square billet using DEFORM 3-D software through cosine shaped die using Al-6062 rigid-plastic material model.
- ✓ The Strain-effective (mm/mm), The Strain Rate-effective (mm/mm/sec), The Stress-effective (MPa), the stress- max principal (MPa), the Velocity-Total (mm/sec), the temperature distribution during deformation has been determined from FEM modeling.
- ✓ The Extrusion load and Pressure both for Al-6062 are more as compare to the Tellurium Lead for extrusion process.

REFERENCES

[1] Maity, K.P., Rout, A.K. and Majhi, K., *“computer –aided simulation of metal flow through curved die for extrusion of square section from square billet”*, Scientific/Industrial journal, (2009): pp.1-10

[2] Richmond, O. and Devenpeck, M.L., *“A die profile for maximum efficiency in strip drawing”*, proc. 4th U.S. Congr., Appl. Mech., ASME, pp.1053, 1962.

[3] Richmond, O. and Morrison, H. L., *“Streamlined wire drawing dies of minimum length”*, journal of Mech. Phyys., Solids, 15 (1967): pp.195,

[4] Chen, C. T. and Ling, F. F., *“Upper bound solutions to axisymmetric extrusion problems”*, Int. Journal of Mechanical science, 10 (1970): pp.311.

[5] Chang, K. T. and Choi, J. C., *“Upper bound solutions to axisymmetric extrusion problems through curve die”*, proc. The 12th Midwestern Mech. Comf. Univecity of Notre dame, 1971.

[6] Meta-Pientri, E. and Friach, J., *“Metal flow through various mathematically contoured extrusion dies,”* Proceedings, North America, Metal-working Research Conf., 5, 1977.

[7] Friach, J. and Mata-Pietric, E., *“Experiments and the upper bound solution in axisymmetric extrusion”*, Proc. IMTDR conference, 18 (1977): pp.55.

[8] Lee, S.K., Ko, D. C. and Kim, B. M.,*”Optimal die profile design for uniform microstructure in hot extrudedproduct”*, International Journal of Machine Tools & Manufacture, 40, (2000): pp.1457-78

[9] Reinikainen, T., Andersson, K., Kivivuori, S., and Korhonen, A. S., *“Finite-element analysis of copper extrusionprocesses”*, Journal of Materials Processing Technology, 34 (1992): pp.101-8

[10] Zhao, D., Zhao, H. and Wang, G., *“Curvilinear integral of the velocity field of drawing and extrusion through elliptical die profile”*, Rolling Technology and Tandem Rolling Automation National Key Lab, Northeastern University, Shenyang, 5, pp.1-5.

[11] Ameed, A. S., Hwyyin, R. N. and Kadhim, H.K., *“Three- Dimensional Analysis of Extrusion in Complex Die by Using Upper Bound theory”*, Engg. & Tech. Journal, 29 (4) (2011): pp.639-50.

[12] Maity, K. P., Kar, P. K. and. Das, N. S., *“A class of upper-bound solution for extrusion of square shapes from square billets through curved dies”*, Department of mechanical Engineering, Regional Engineering College, Rourkela, Orissa, India, pp.1-6.

[13] Samanta, S. K., *“Slip-line field for extrusion through cosine-shaped dies”*, *J. Mech. Phys.*, 18 (1973): pp.311.

[14] Yih, C.S., *"Stream Functions in Three-Dimensional Flow"*, La Haulle Blanche, 12 (1957): pp.445.

[15] Zhao, H., He-nan, W., Meng-jun, W., and Guang-yao, L., *"Simulation of extrusion process of complicated aluminum profile and die trial"*, Trans. Nonferrous Met. Soc. China, (2012): pp. 1732-7

[16] Hong, Y., Zhong-xu, B. and He-sheng, L., *"Study progresses on aluminum profile extrusion die CAD/CAE/CAM"*, Journal, Light Alloy Fabrication Technology, (1999): pp.1−4

[17] Gao-yong, L., Jia, Z. and Xiao-yan, Z., *"Numerical simulation of extrusion process of X5214 aluminum alloy profile"*, Journal of Central South University Technology, 39 (4) (2008): pp.748−54.

[18] Li, G., Jinn, J.T. and Wu, W.T., *"Recent development and applications ofthree-dimensional finite element modeling in bulk forming process"*, Journal of Materials Processing Technology, 113 (2001): pp.40−5.

[19] Zhou, J., Li, L., and Duszczyk, J., *"3D FEM simulation of the wholecycle of aluminum extrusion throughout the transient state and thesteady state using the updated Lagrangian approach"*, Journal of Materials Processing Technology, 134 (2003): pp.383−97.

[20] Chanda, T., Zhou, J., and Duszczyk, J., *"FEM analysis of aluminum extrusion through square and round dies"*, Materials and Design, 21 (2000): pp.323−35.

[21] Gouveia, B.P.P.A., Rodrigues, J.M.C., Bay, N. and Martins, P.A.F., *"Deformation analysis of the round-to-square extrusion a numerical and experimental investigation"*, Finite Elements in Analysis and Design, 35 (2000): pp.269-82.

[22] Kuester, J. L. and Mize, J. H., *"Optimization Techniques with Fortran"*, McGraw Hill Book Company.

[23] DEFORM TM 3D Version 6.19sp20, *"User's manual"*, scientific Forming technologies Comporation, 2545 Farmers Drive, Suite 200, Columbus, Ohio, 2008, 43235.

[24] Bogale, K., *"Extrusion Dies Design and simulation"*, Degree thesis, Plastic Technology (2011).

[25] Chaubey, S., *"Modeling and Design of Die Profile of Extrusion of square section from round billet through non-linear converging Dies"*, M. Tech. thesis, Department of Mechanical Engineering, National institute of Technology, Rourkela, (2011).

[26] Tirkey, S.K., *"Three dimensional analysis of lateral extrusion of some complex forms"*, M. Tech. thesis, Department of Mechanical Engineering, National institute of Technology, Rourkela, (2007).

[27] Murmu, M.K., *"Three dimensional analysis of extrusion through taper die"*, M. Tech. thesis, Department of Mechanical Engineering, National institute of Technology, Rourkela, (2009).

[28] Matamoros, C.F.C., *"Modeling and control for the isothermal extrusion of Aluminum"*, for the Doctor of Technical Sciences, Swiss Federal Institute of Technology Zurich, (1999).

[29] Rout, A.K., *"A class of a solutions for extrusion through converging Dies"*, Ph.D. dissertation, Department of mechanical Engineering, National institute of Technology, Rourkela, 2010.

[30] Skoog, G., Antonson, E., Nilson, G. and Sundgren, M., *"Performing materials for Aluminium extrusion components"*, Uddenholm Machining AB, Hagfors Sweden.

[31] Aubert and Duval, *"A new Die material for longer service life"*, Tour Maine Montparnasse 33, avenue du Maine 7575 Paris Codex 15 France (www.aubertduval.com) 02/2012.